

Understanding Agricultural and Urban Land Cover Impacts on Regional Climate



Dr. Michael Puma
GISS Lunch Seminar
7th Floor Conference Room
28 March 2012

Before we start...

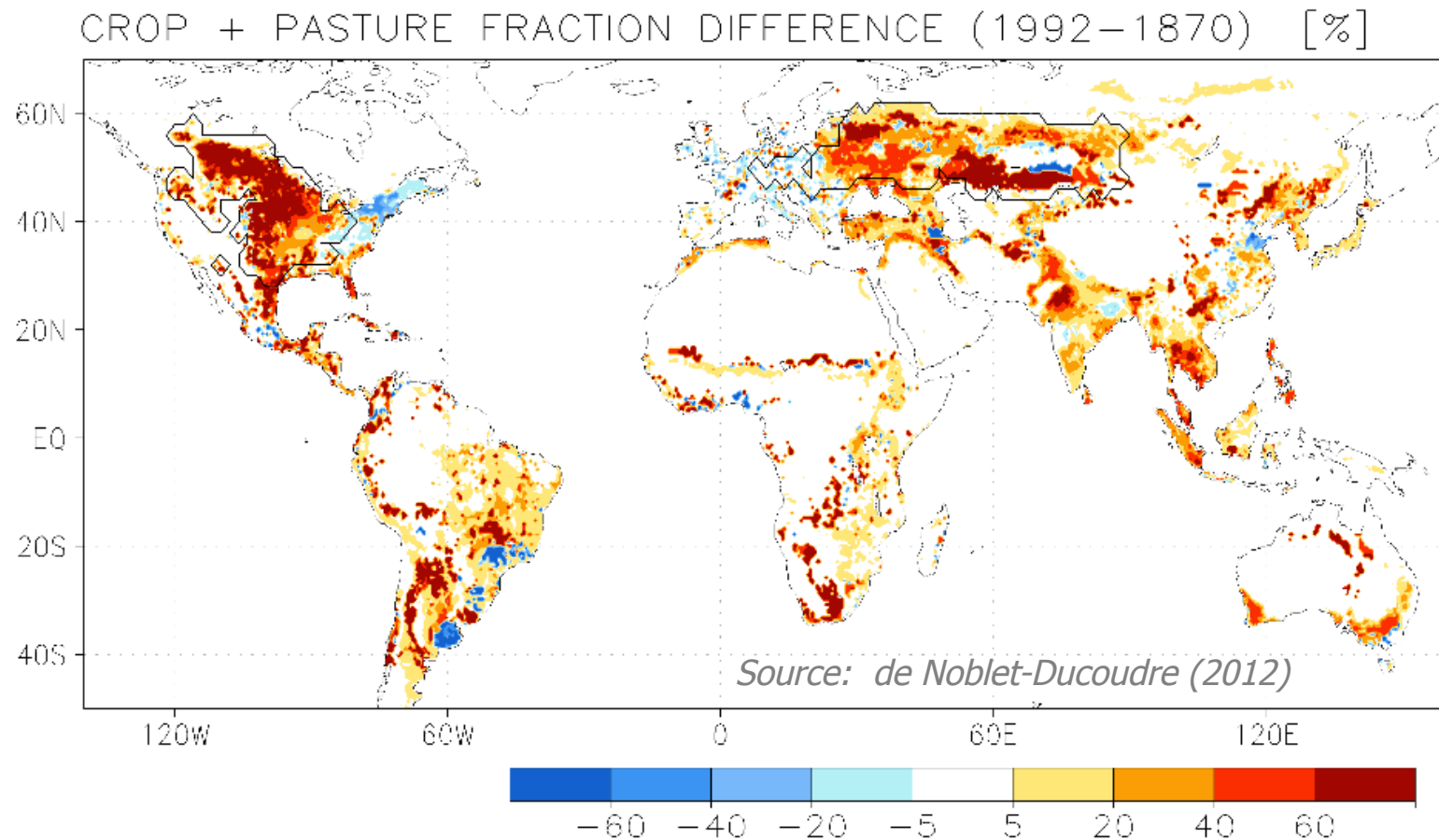
- **LULCC** stands for **L**and-**U**se induced **L**and-**C**over **C**hange; it's a general term for the human modification of Earth's terrestrial surface
- Refers mainly to conversion of natural forests or natural grasslands for urbanization and agriculture
- Acronyms aren't always helpful, so we'll go with **land change** for today...



Regional importance of land change

- Most experiments => land change has a negligible global signature
- BUT consider *intense land change* – where it has transformed large regions of the Earth's surface => a spatially organized change by region
- **Relevant Research Question:** Are climate impacts *in regions with intense land change* worth accounting for when exploring the impact of other human forcings (ie GHGs) on regional climate?
 - *NOT whether land change has a globally-averaged significant impact*

Changes in crop/pasture extent



Red: increase in human areas

Blue: decrease in human areas

Land use/land cover changes and climate: modeling analysis and observational evidence

Roger A. Pielke, Sr.,^{1*} Andy Pitman,² Dev Niyogi,^{3,4}
Rezaul Mahmood,⁵ Clive McAlpine,⁶ Faisal Hossain,⁷
Kees Klein Goldewijk,⁸ Udaysankar Nair,⁹ Richard Betts,¹⁰
Souleymane Fall,¹¹ Markus Reichstein,¹² Pavel Kabat¹³ and
Nathalie de Noblet¹⁴

This article summarizes the changes in landscape structure because of human land management over the last several centuries, and using observed and modeled data, documents how these changes have altered biogeophysical and biogeochemical surface fluxes on the local, mesoscale, and regional scales. Remaining research issues are presented including whether these landscape changes alter large-scale atmospheric circulation patterns far from where the land use and land cover changes occur. We conclude that existing climate assessments have not yet adequately factored in this climate forcing. For those regions that have undergone intensive human landscape change, or would undergo intensive change in the future, we conclude that the failure to factor in this forcing risks a misalignment of investment in climate mitigation and adaptation. © 2011 John Wiley & Sons, Ltd.



- Historic land change (mainly deforestation) tends to **increase** the **surface albedo** resulting in **cooling**

- Deforestation **decreases ET efficiency** and **surface aerodynamic roughness** => tends to cause **warming** by suppressing turbulent energy fluxes

de Noblet-Ducoudré (2012) Intercomparison



- 1 **Determining robust impacts of land-use induced land-cover**
- 2 **changes on surface climate over North America and Eurasia; Results**
- 3 **from the first set of LUCID experiments**

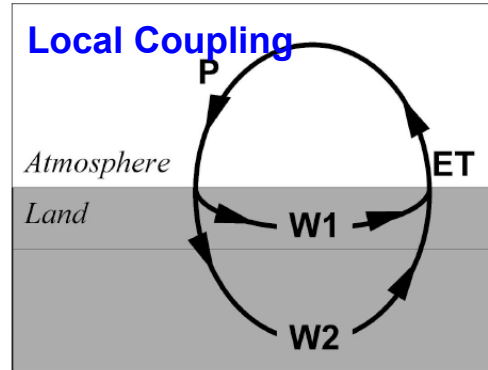
4 **Nathalie de Noblet-Ducoudré¹**

- Seven atmosphere-land models
- “a common experimental design to explore those impacts of LULCC that are robust and consistent across the climate models”

de Noblet-Ducoudré (2012) Intercomparison

- Variability from land change > from GHG increases
- Robust common features:
 - Amount of available energy used for turbulent fluxes
 - Changes in response to land change depend almost linearly on the fraction of trees removed
- No consistency on the partitioning of available energy between latent and sensible heat fluxes

Model-dependent land-atmosphere coupling



- Model differences (coupling strengths) are related to
 - Variance of evapotranspiration (ET) over land → *how soil moisture controls ET*
 - Precipitation parameterizations and its respond to ET changes
- Process is not entirely local
 - Advection and the general circulation of the atmosphere transport water and moist static energy horizontally
- Land horizontal transports in rivers and by irrigation

Outline

- I. Irrigation and climate
- II. Deforestation and climate
- III. Urbanization and climate
- IV. Land-Atmosphere Research Program at GISS

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Program at GISS

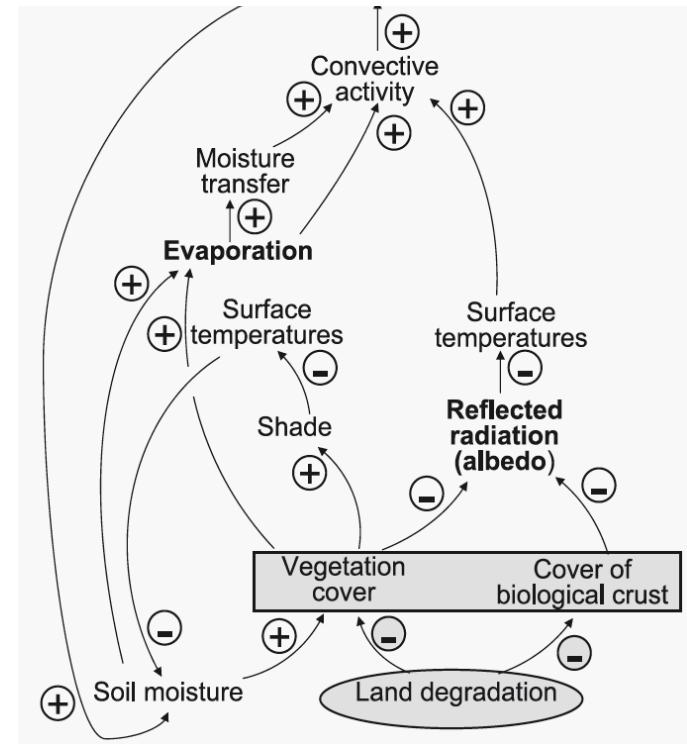
How has irrigation modified climate over the 20th Century?

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, D16120, doi:10.1029/2010JD014122, 2010

Effects of irrigation on global climate during the 20th century

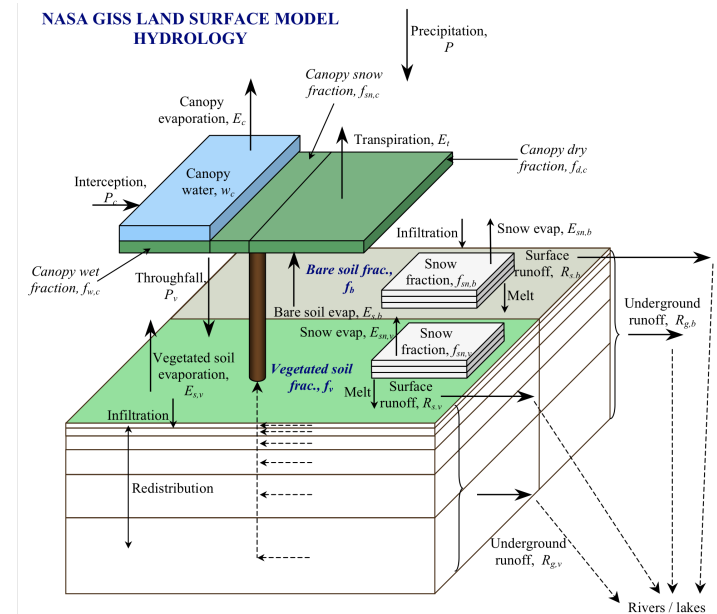
M. J. Puma^{1,2} and B. I. Cook^{2,3}

- Irrigation modifies energy and water budgets
- Potentially leads to:
 - Lower temperature
 - Higher humidity
 - Increased convection (contributes heat to destabilize boundary layer)



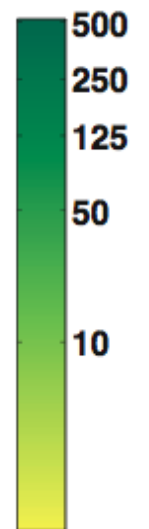
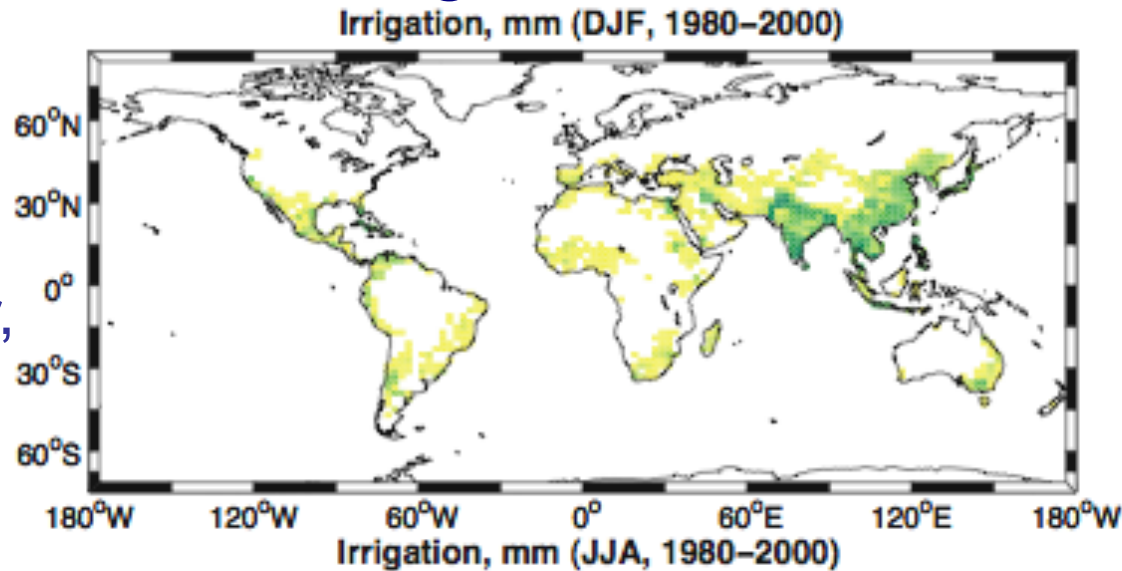
Irrigation in ModelE

- Two 5-member ensemble simulations (IRRIG, CTRL)
- 2° lat x 2.5° long
- Observed SSTs
- Irrigation is added as a flux to the top of the vegetated soil column
- Irrigation water/energy (*withdrawn from lakes/rivers*)
- If insufficient, then remaining water is added to the system (*fossil water*)

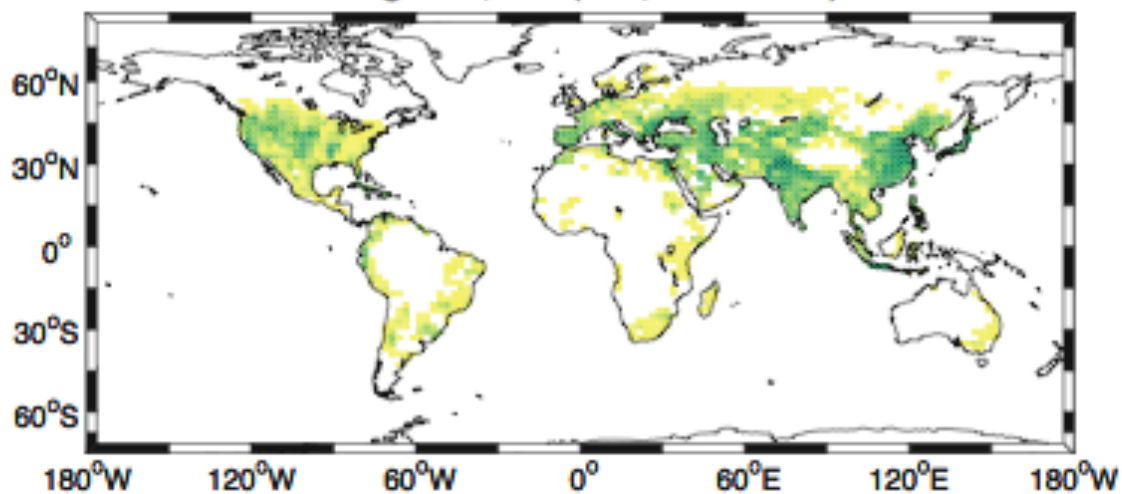


Seasonal total irrigation

DJF:
December,
January,
February

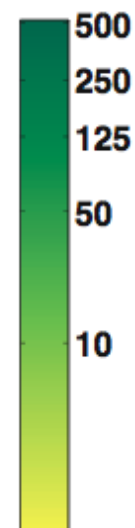
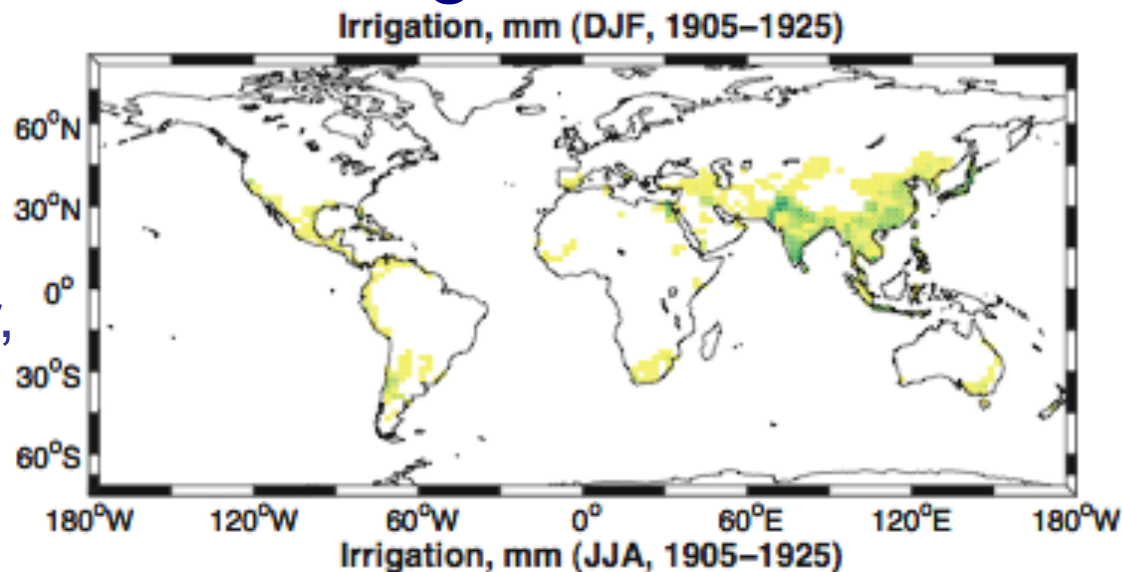


JJA:
June,
July,
August

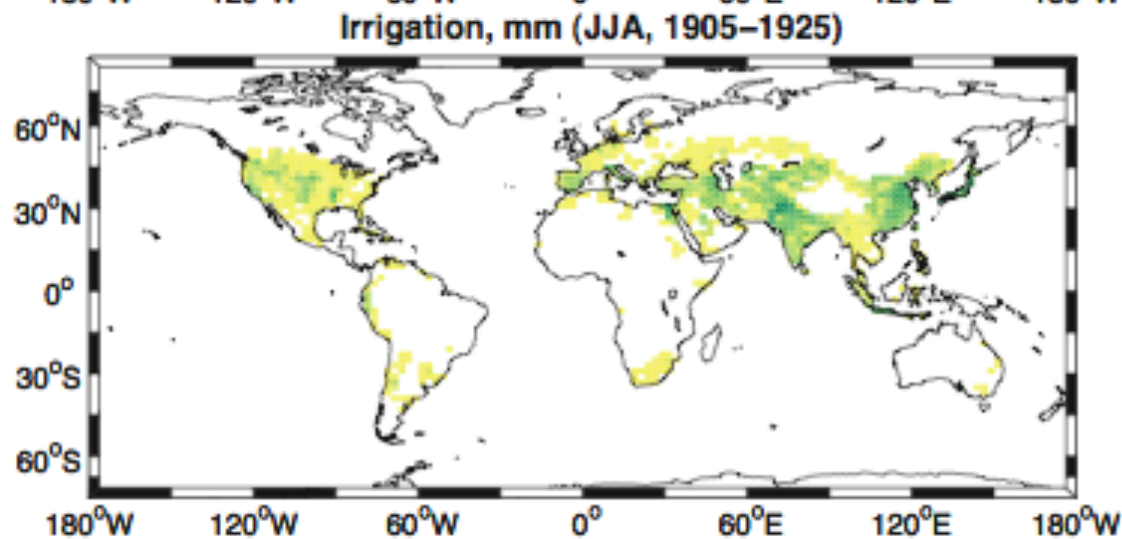


Seasonal total irrigation

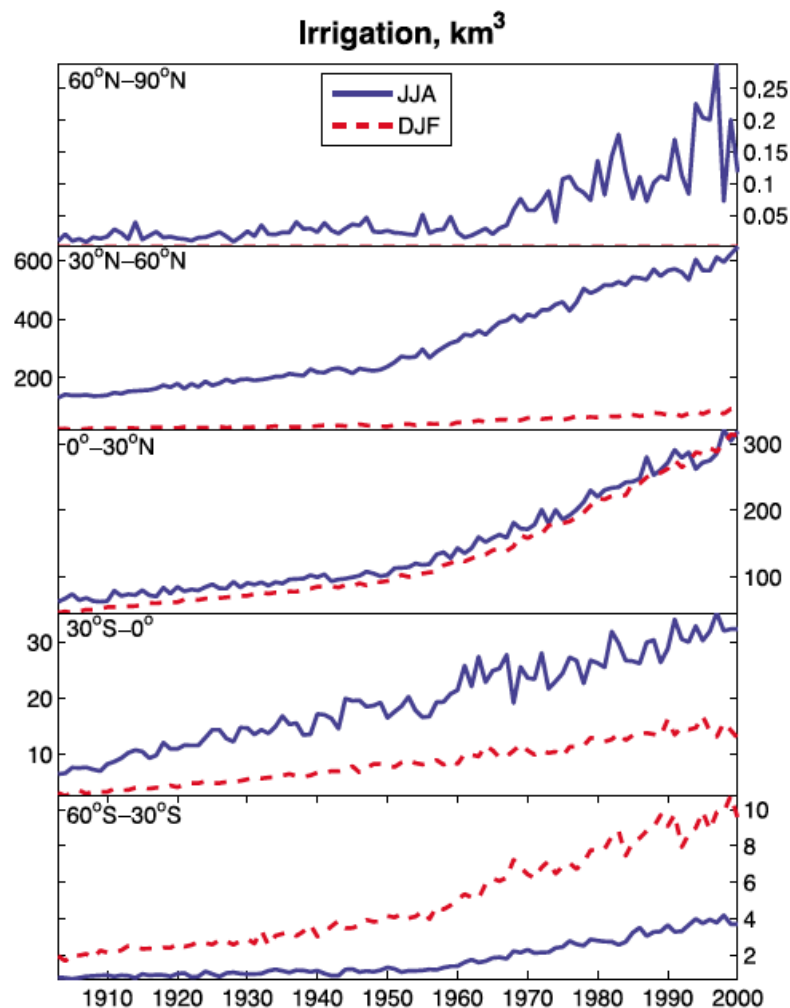
DJF:
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January,
February



JJA:
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July,
August



Seasonal irrigation by latitude band



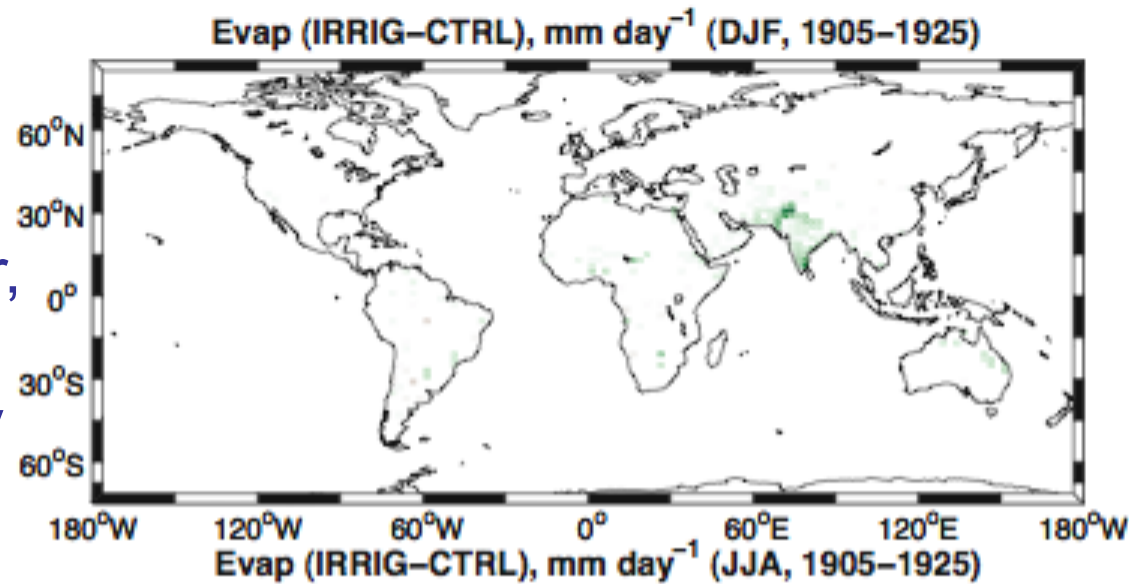
Study	Gross Irrig. (km ³)
Our Study	2565
<i>Sacks et al.</i> [2009]	2560
<i>Lobell et al.</i> [2006]	†
<i>Boucher et al.</i> [2004]	2353‡

JJA – June, July, August

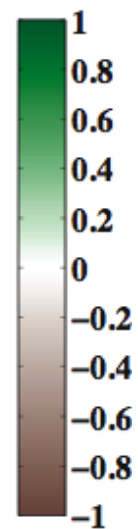
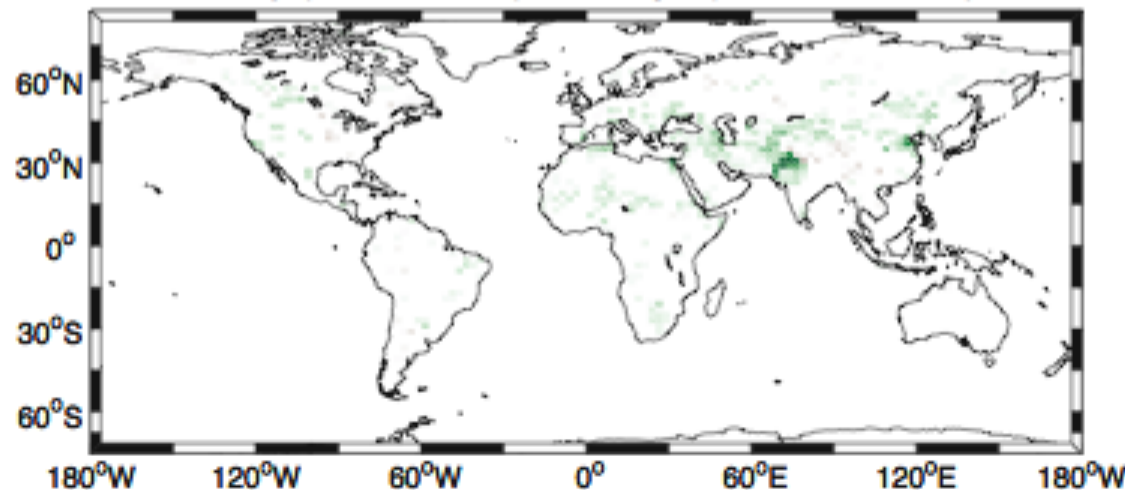
DJF – December, January, February

Seasonal evapotranspiration

DJF:
December,
January,
February



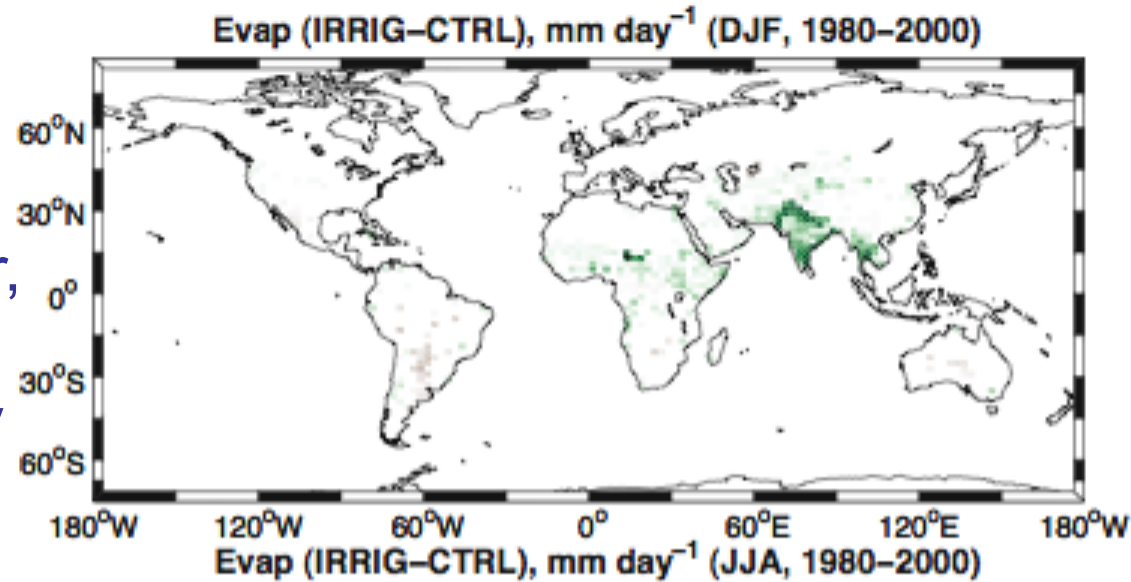
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July,
August



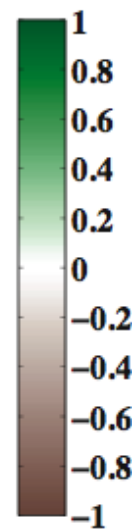
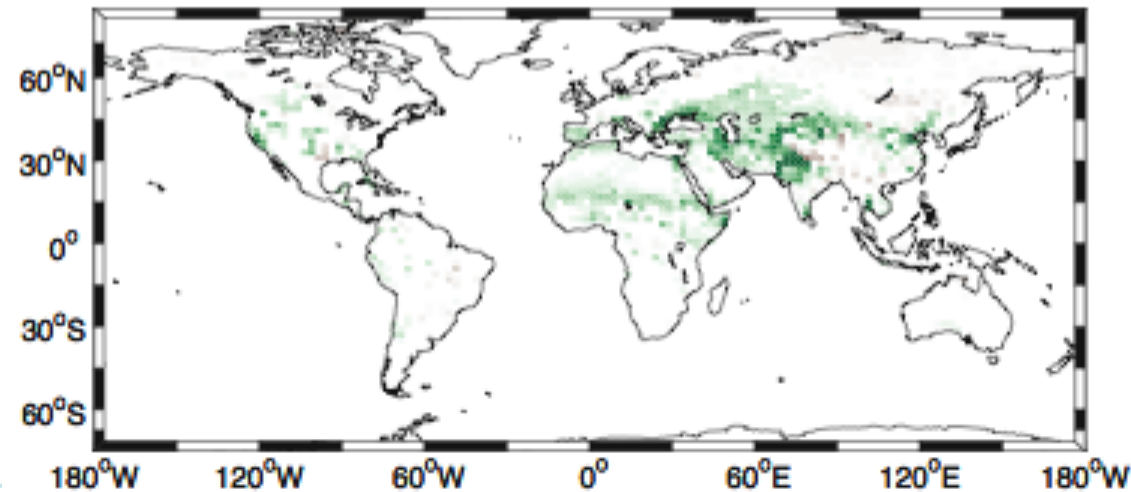
Only land
changes with a
 $p < 0.1$ significance
(based on a two
sample t-test)

Seasonal evapotranspiration

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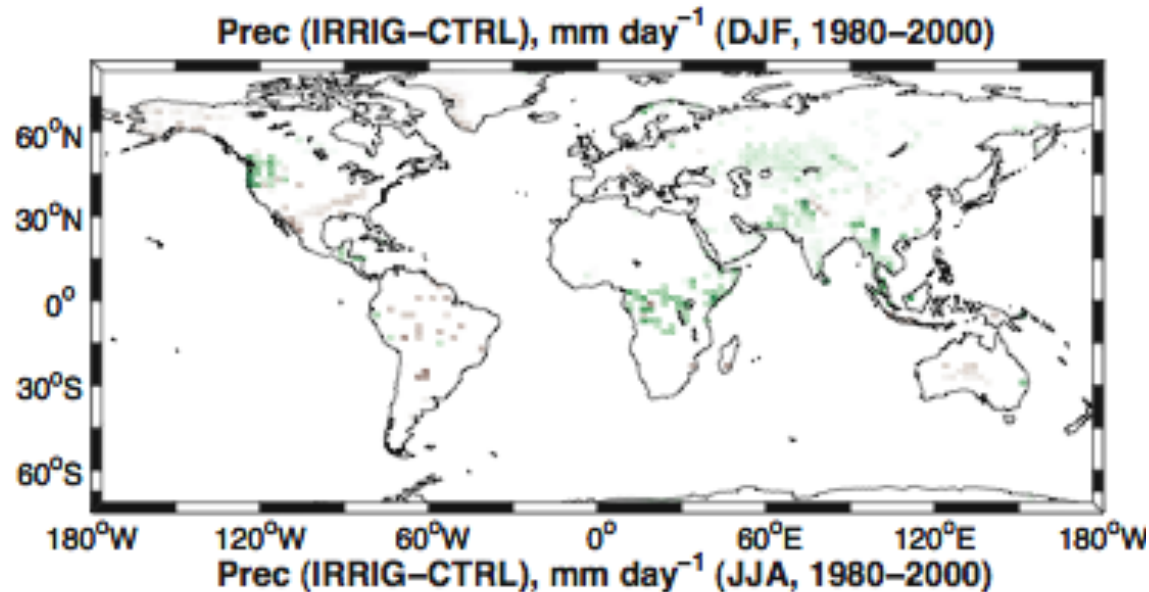
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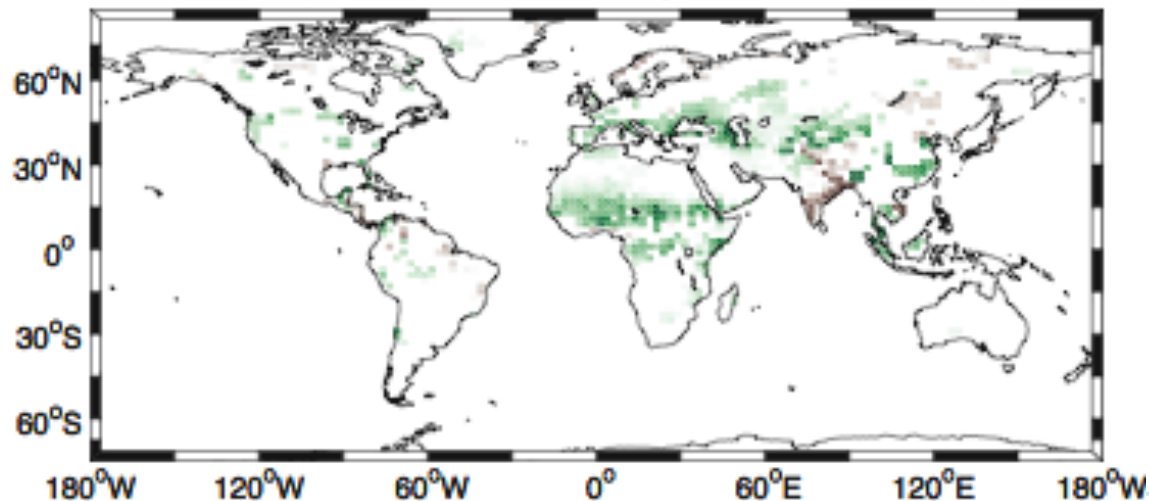
Only land
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sample t-test)

Seasonal precipitation

DJF:
December,
January,
February

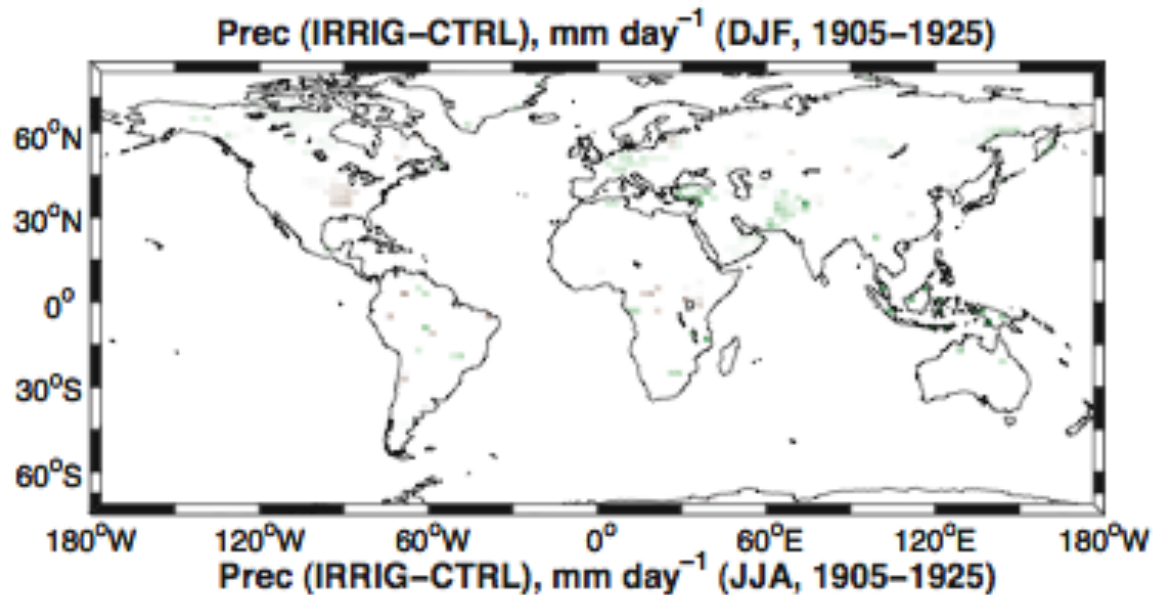


JJA:
June,
July,
August

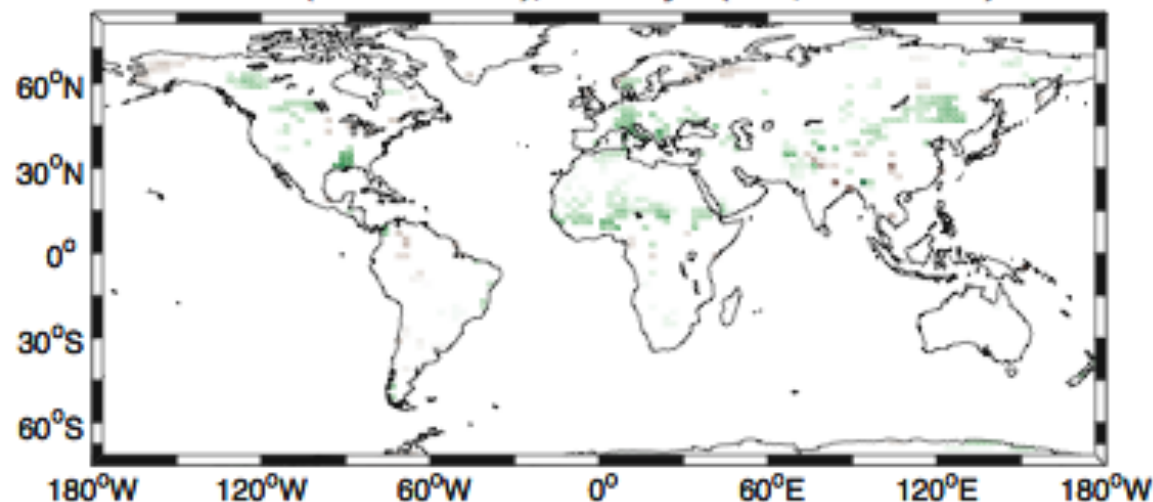


Seasonal precipitation

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January,
February

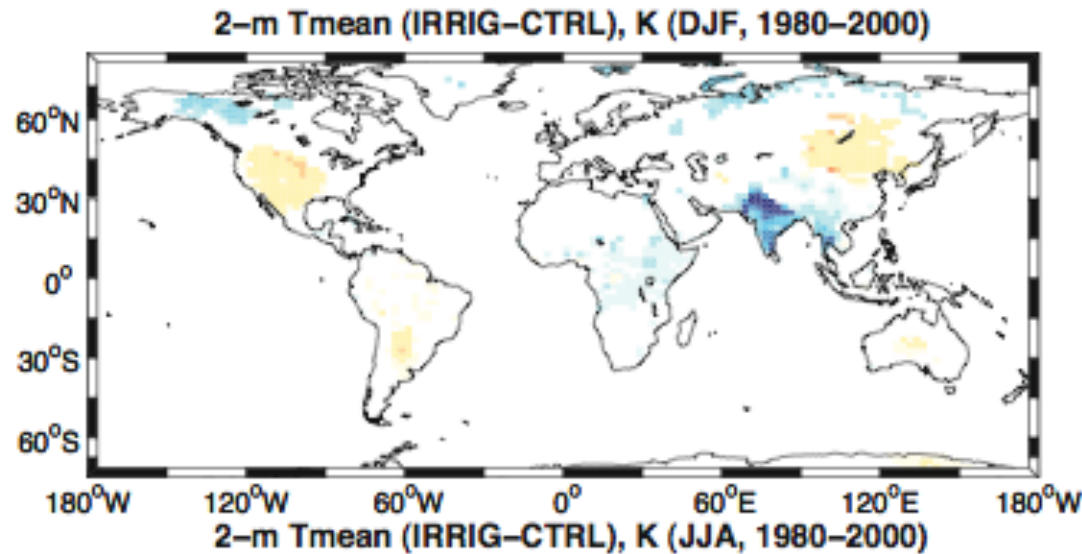


JJA:
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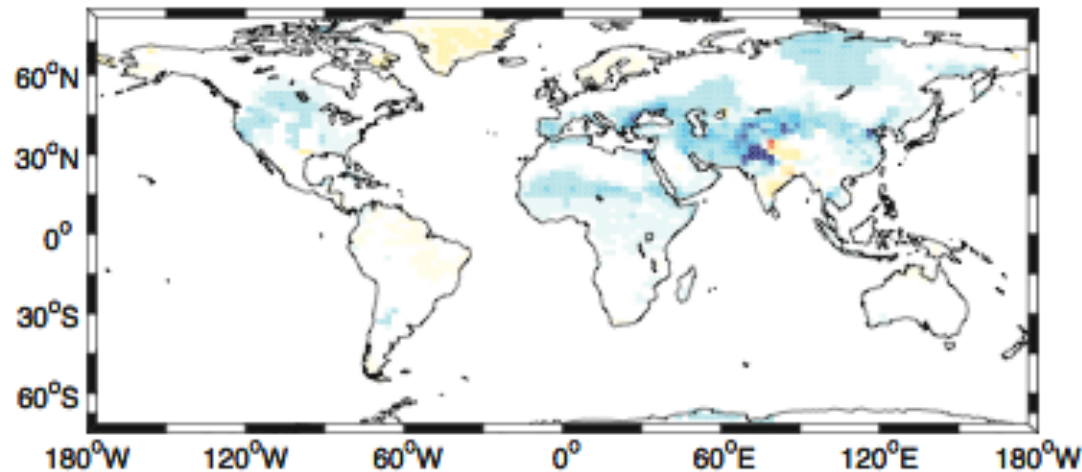


Seasonal 2m air temperature

DJF:
December,
January,
February

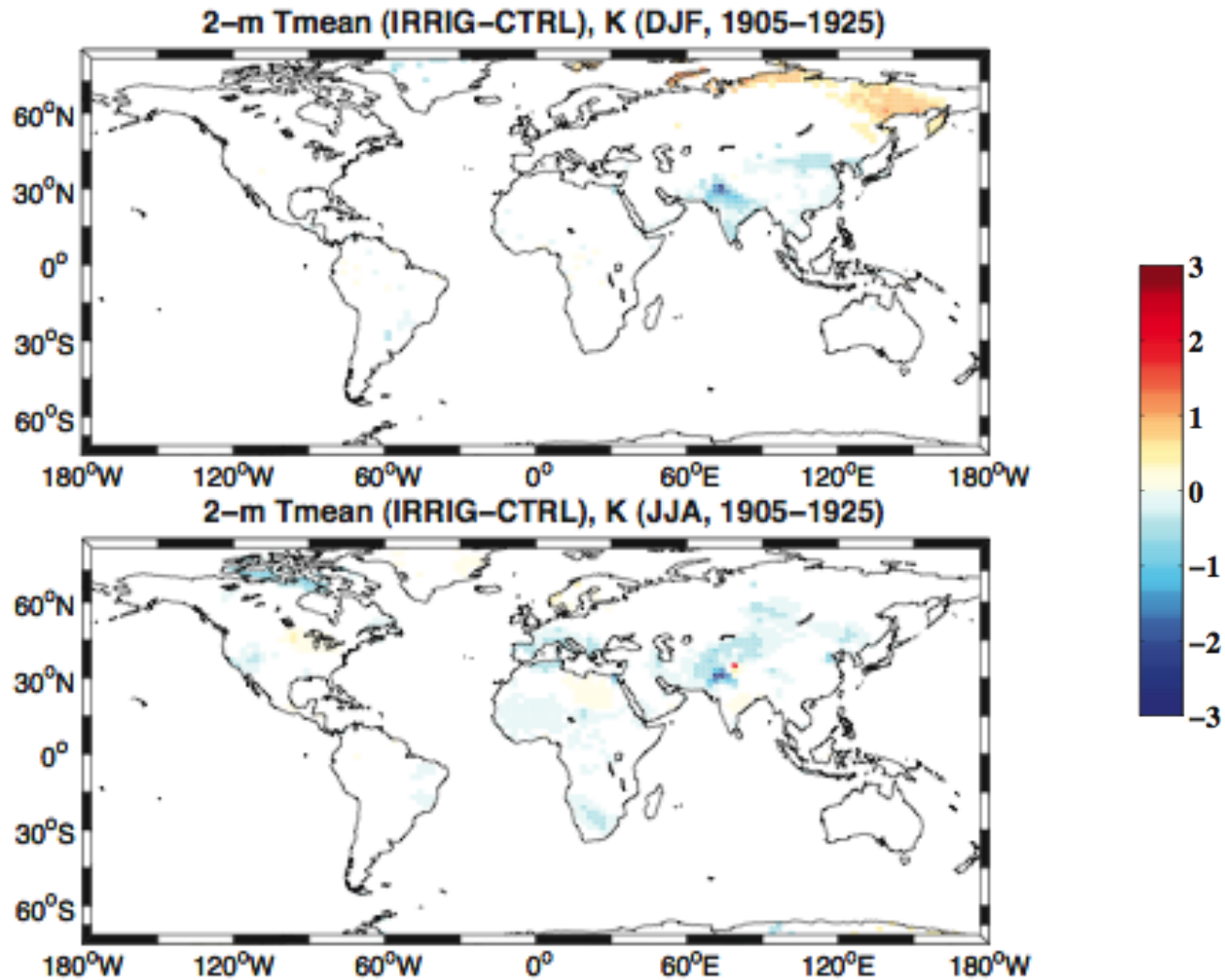


JJA:
June,
July,
August



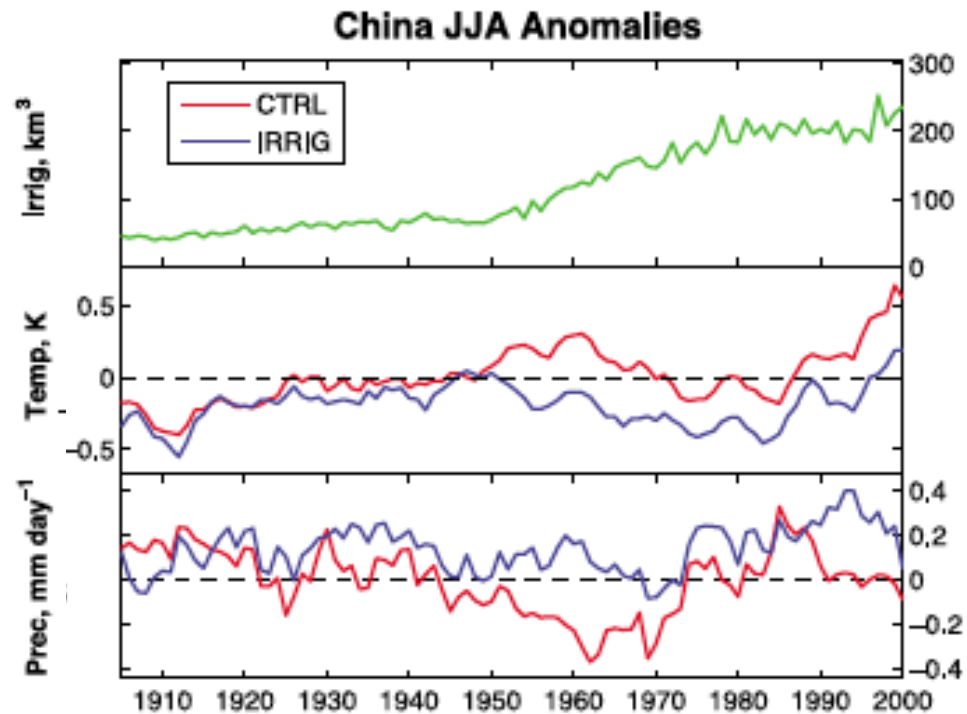
Seasonal 2m air temperature

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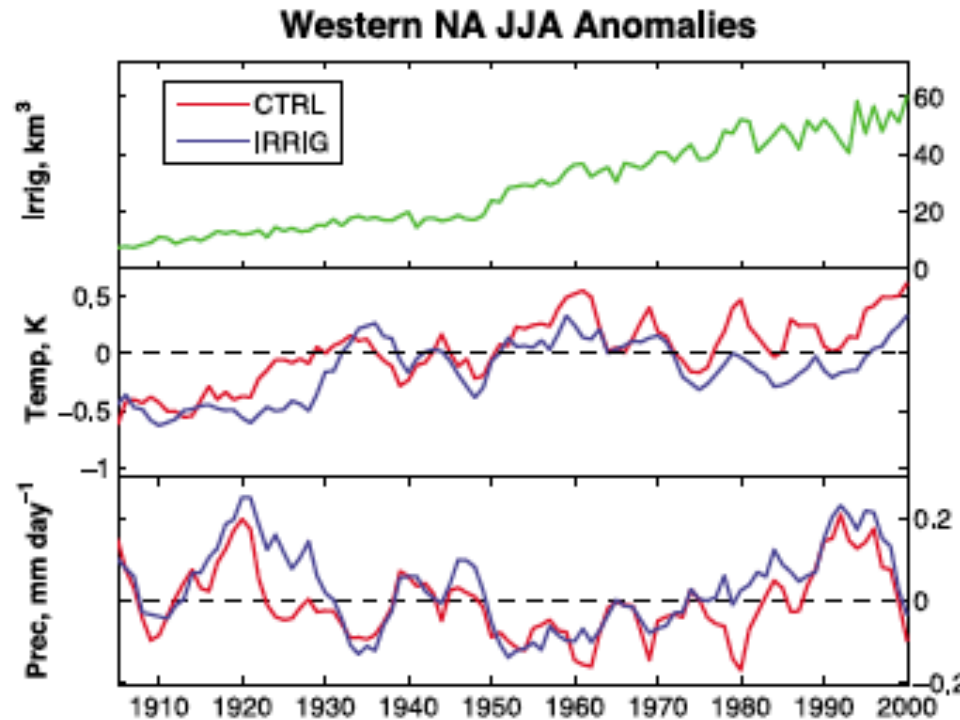
JJA:
June,
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August

Regional effects of irrigation



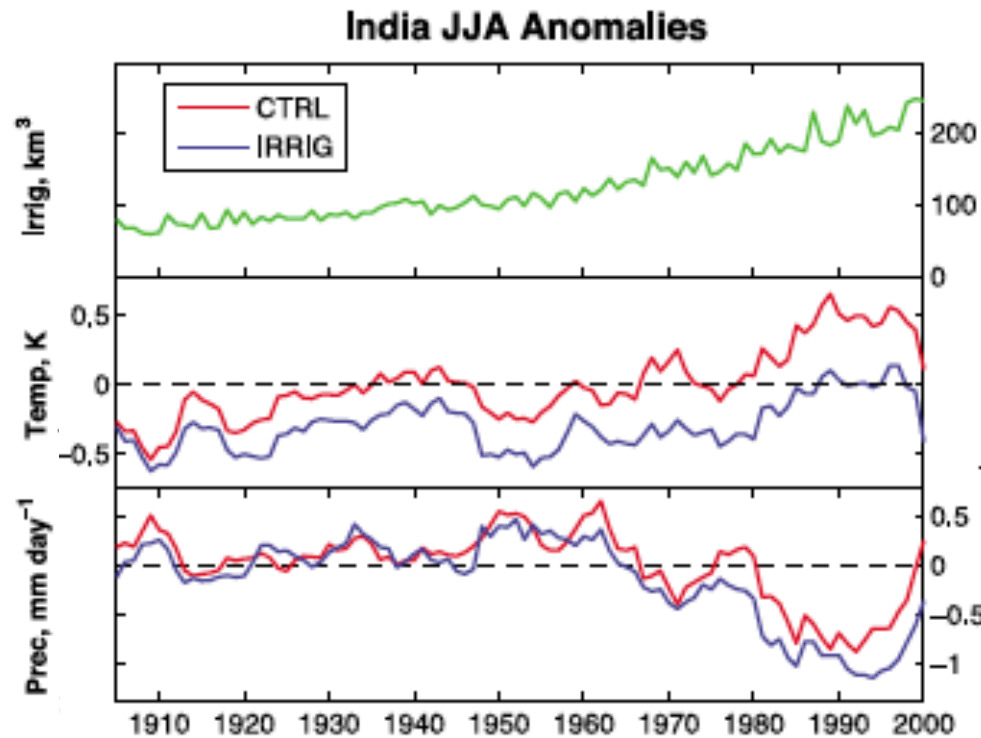
IRRIGATION
CONTROL

Regional effects of irrigation



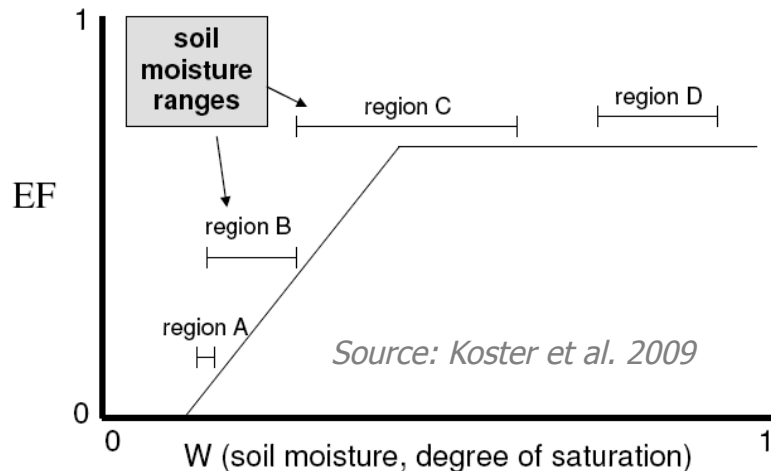
IRRIGATION
CONTROL

Regional effects of irrigation



IRRIGATION
CONTROL

Why different temperature responses?



Evaporative fraction (EF): *ratio of evapotranspiration to net radiation*

$$EF = \frac{Q_e}{Q_e + Q_h} :$$

Q_h = sensible heat flux

Q_e = latent heat flux

Note: Bowen ratio = Q_h/Q_e

Evaporative regimes

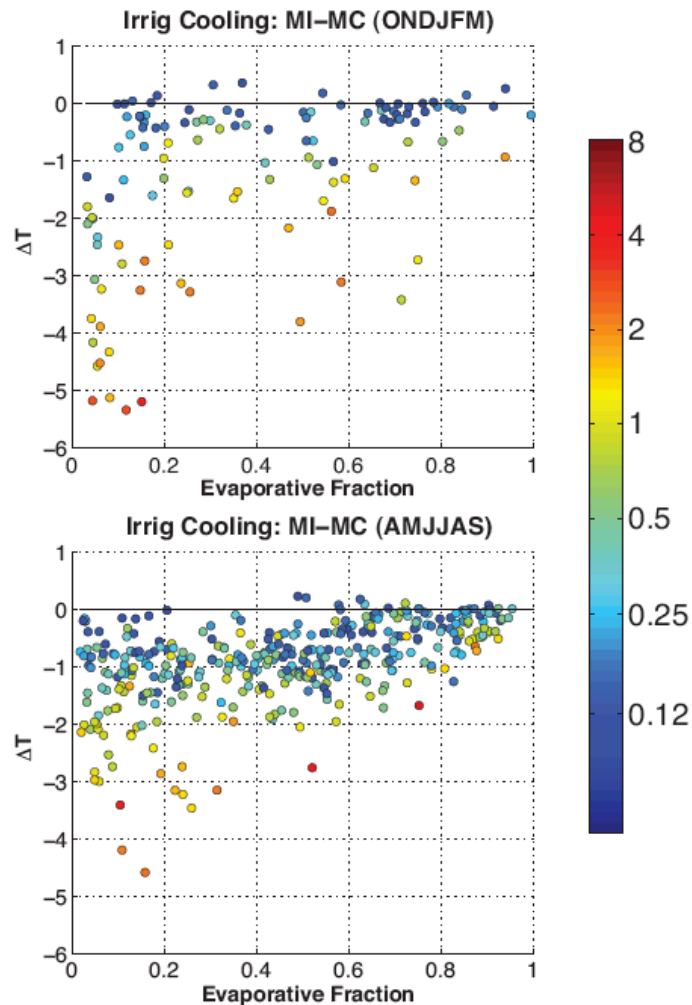
- **Regions A & B:** soil-moisture controlled; irrigation generally increases Q_e and cools surface temperatures
- **Region C:** straddles the two regimes; irrigation can lead to more limited increases in Q_e and more limited cooling
- **Region D:** energy controlled -> irrigation does not impact surface temperatures

Irrigation induced surface cooling in the context of modern and increased greenhouse gas forcing

Benjamin I. Cook • Michael J. Puma •
Nir Y. Krakauer

- What is the cooling effect of irrigation under modern and future greenhouse gas forcing? (*i.e. is there a masking effect and does it change in the future?*)

Irrigation and evaporative fraction



- Irrigation impacts on surface air temperature (MI-MC) related to
 - Irrigation amount (mm/d, indicated by coloring)
 - Evaporative fraction (EF)
- Two periods
 - October to March
 - April to September

Current irrigation-induced cooling

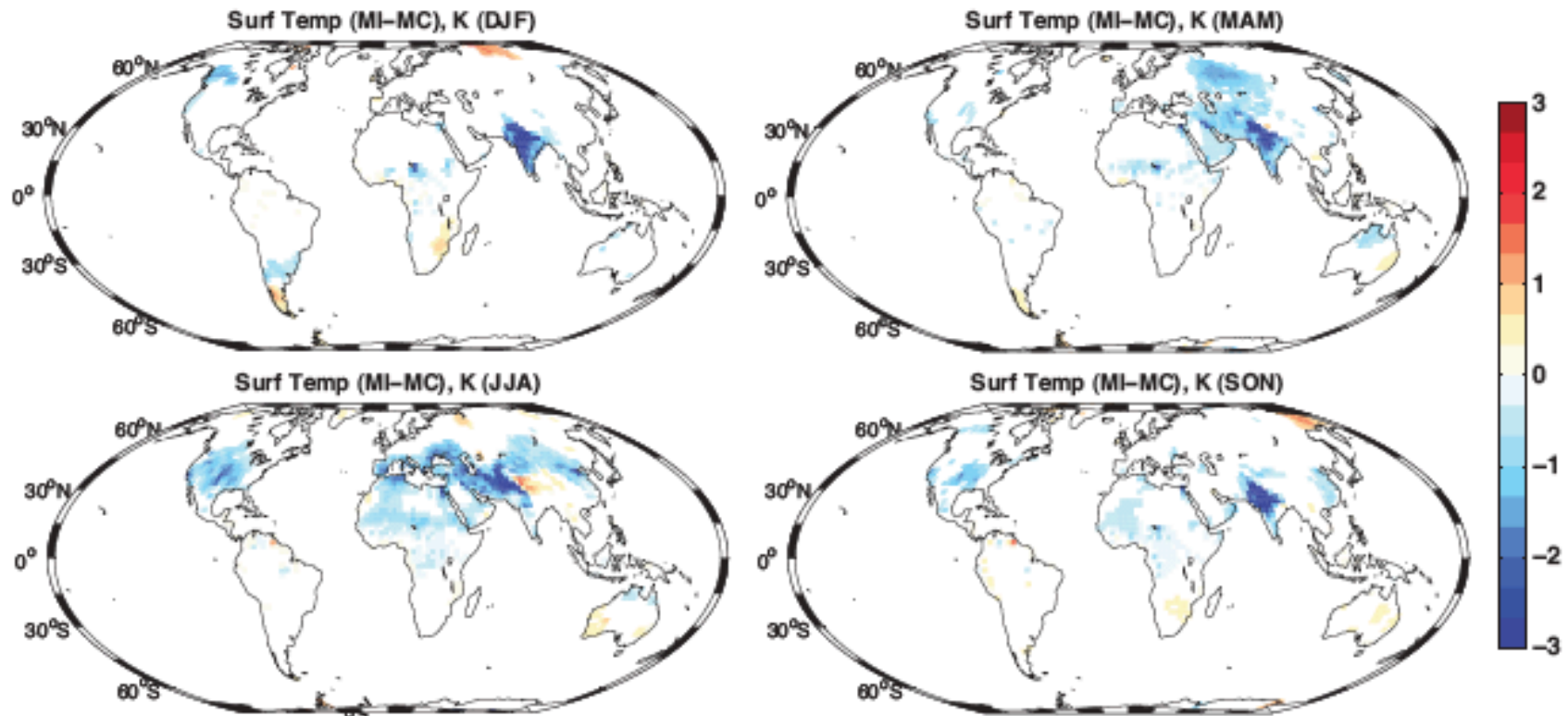


Fig. 6 Differences in surface air temperature (K) over land areas for the modern irrigation comparison (MI-MC). Insignificant differences ($p < 0.10$) are masked out.

MODERN IRRIGATION (MI) – MODERN CONTROL (MC)

Future irrigation-induced cooling

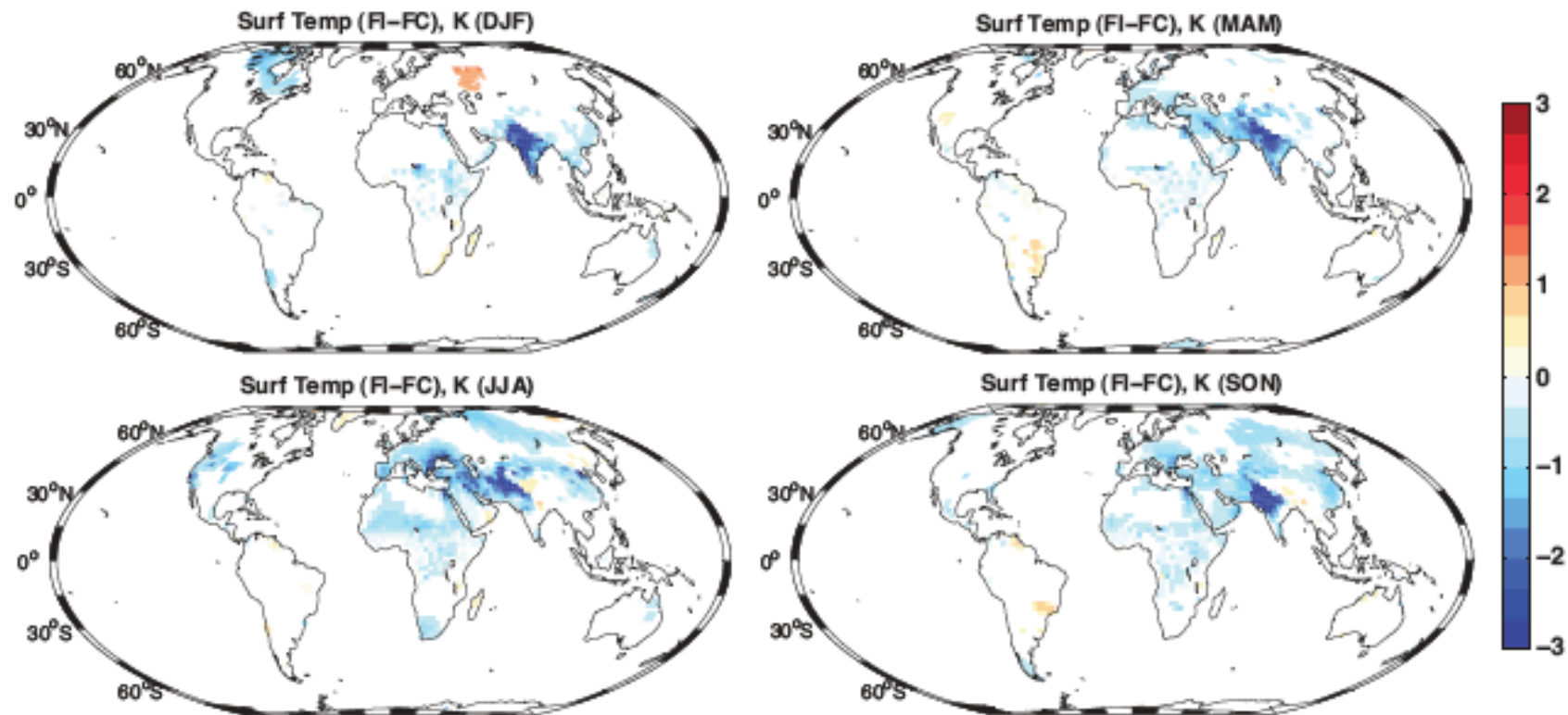
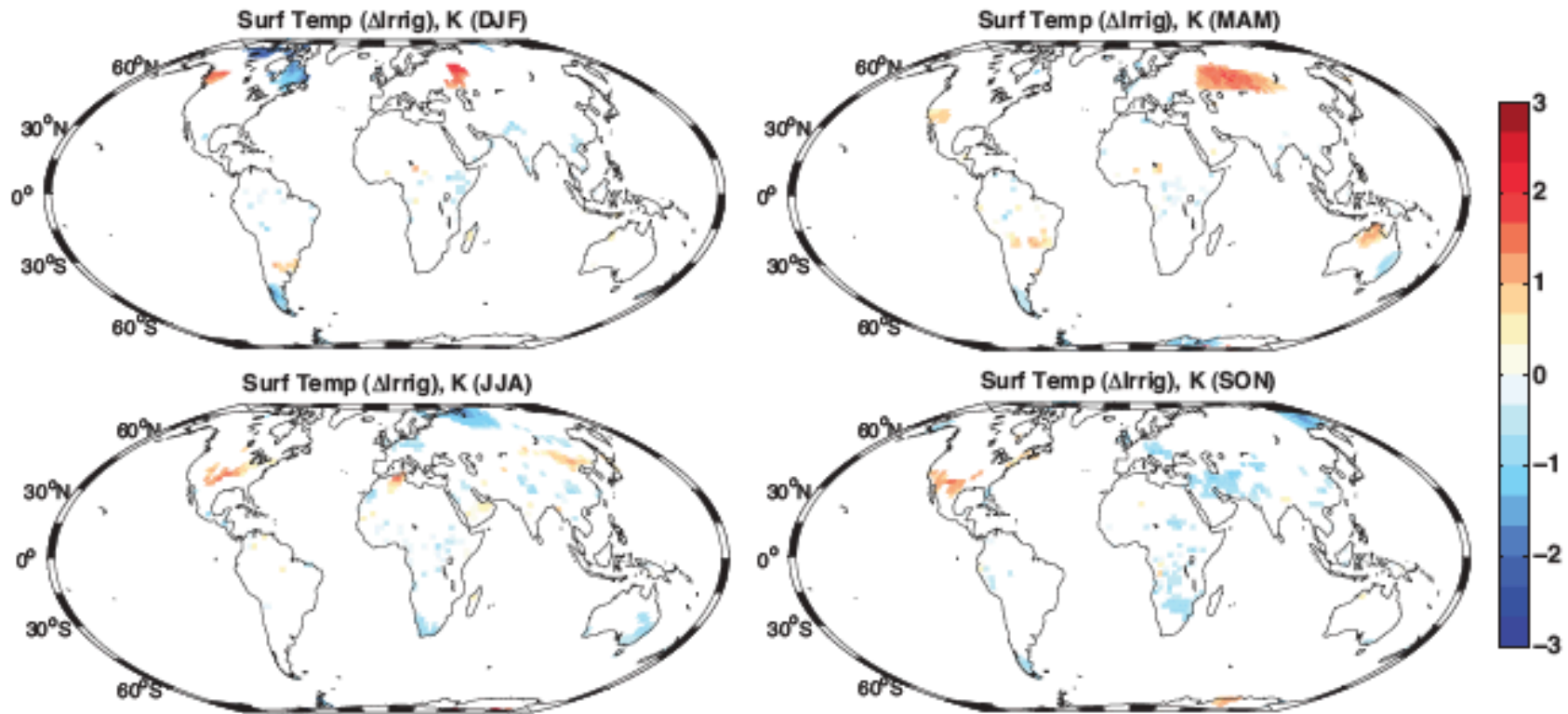


Fig. 10 Differences in seasonal surface air temperature (K) over land areas for the future irrigation comparison (FI-FC). Insignificant differences ($p < 0.10$) are masked out.

FUTURE IRRIGATION (FI) – FUTURE CONTROL (FC)

What's changed?



$(FI - FC) - (MI - MC)$:

Red indicates cooling effect diminished under future climate;

Blue areas indicate the magnitude increases under future climate

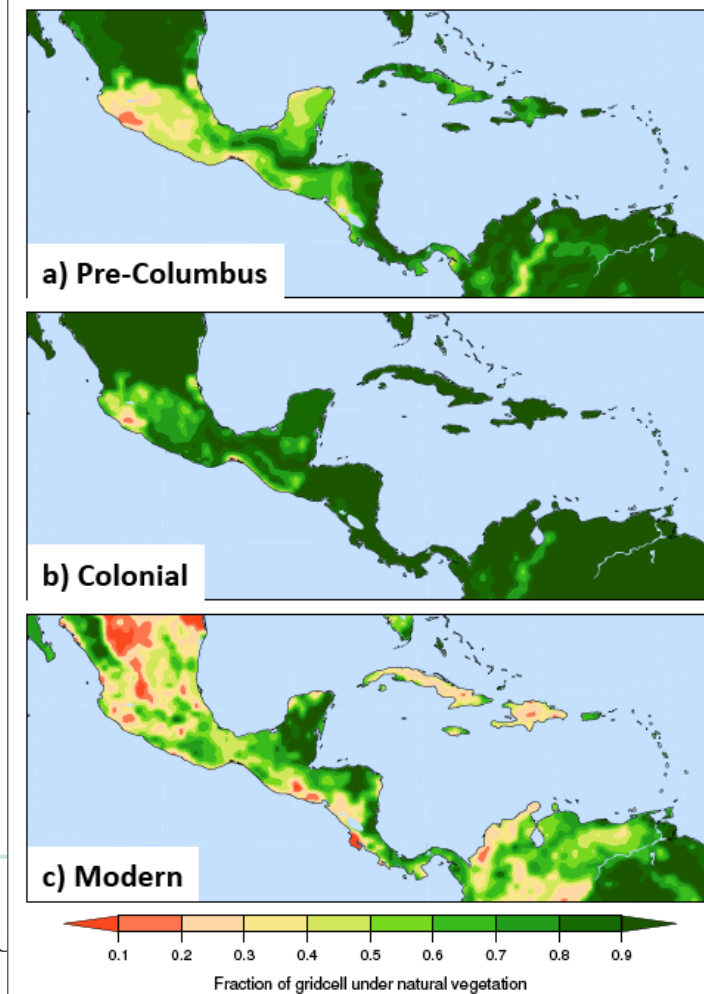
Outline

- I. Irrigation and climate
- II. Deforestation and climate**
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Program at GISS

Pre-Columbian deforestation as an amplifier of drought in Mesoamerica

Benjamin I. Cook^{1,2}, Kevin J. Anchukaitis², Jed O. Kaplan³, Michael Puma¹, Maxwell Kelley¹, &

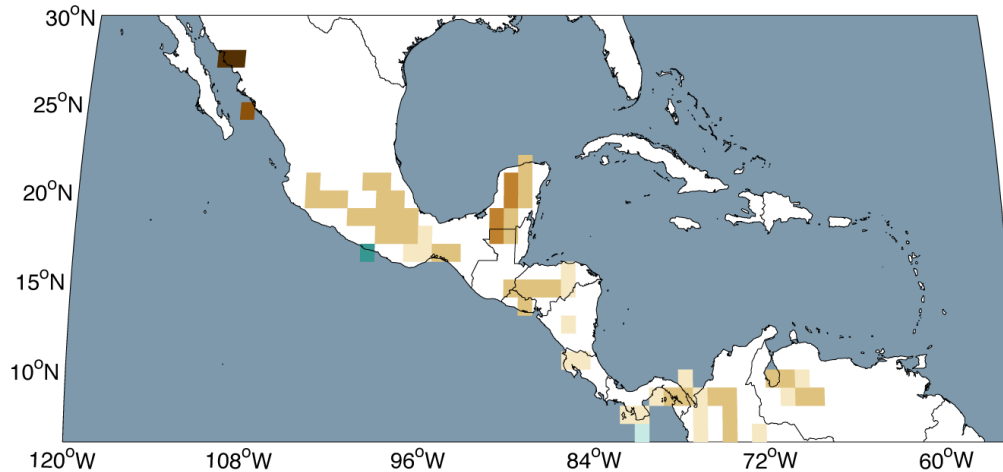
Denis Gueyffier⁴



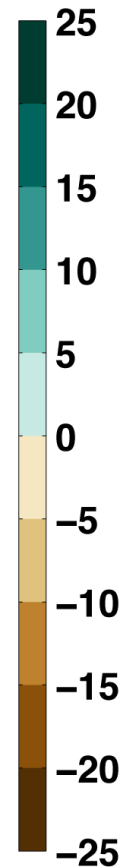
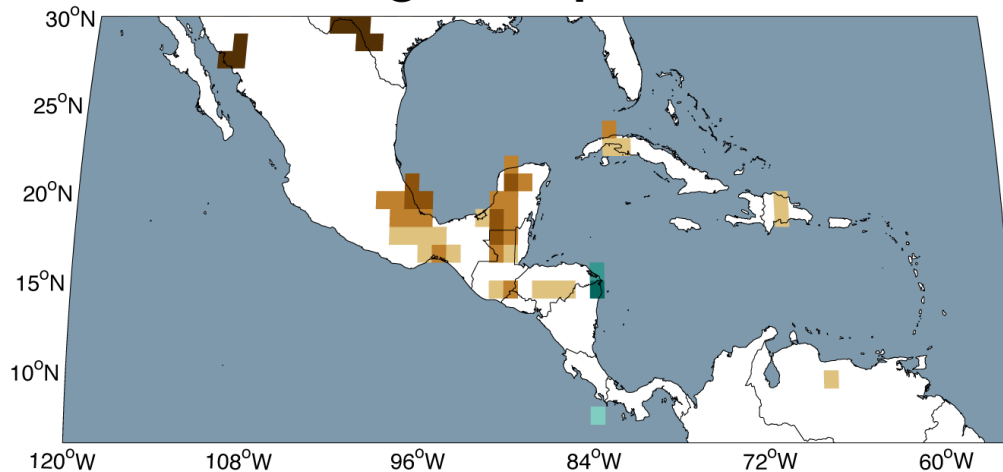
- Droughts in pre-Columbian Mesoamerica have been linked to significant upheavals in civilizations
- May be linked to extensive deforestation associated with agriculture

Precip, DEFOREST-NATVEG (%)

Annual



August-September



Suggest that pre-Columbian deforestation biased the climate towards a drier mean state and amplified drought conditions in the region

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Simple urban model

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JOURNAL OF APPLIED METEOROLOGY AND CLIMATOLOGY

VOLUME 47



An Urban Parameterization for a Global Climate Model. Part I: Formulation and Evaluation for Two Cities

K. W. OLESON AND G. B. BONAN

Climate and Global Dynamics Division, National Center for Atmospheric Research,* Boulder, Colorado

J. FEDDEMA

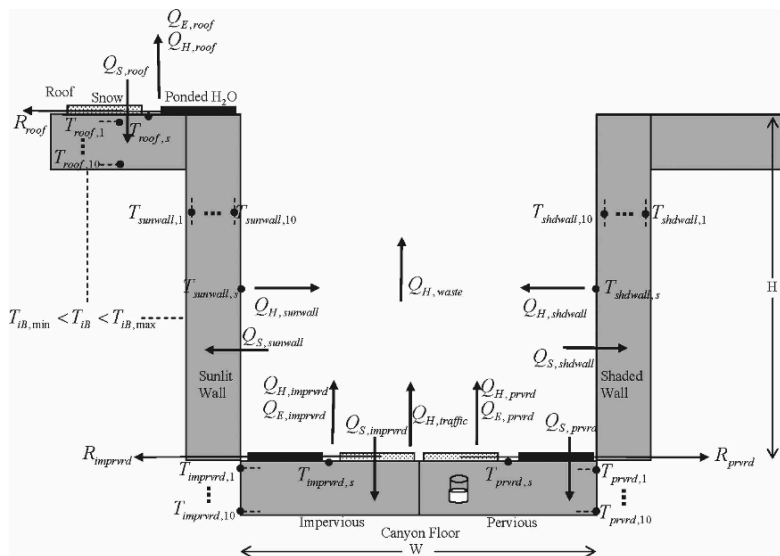
Department of Geography, University of Kansas, Lawrence, Kansas

M. VERTENSTEIN

Climate and Global Dynamics Division, National Center for Atmospheric Research,* Boulder, Colorado

C. S. B. GRIMMOND

Department of Geography, King's College, London, United Kingdom

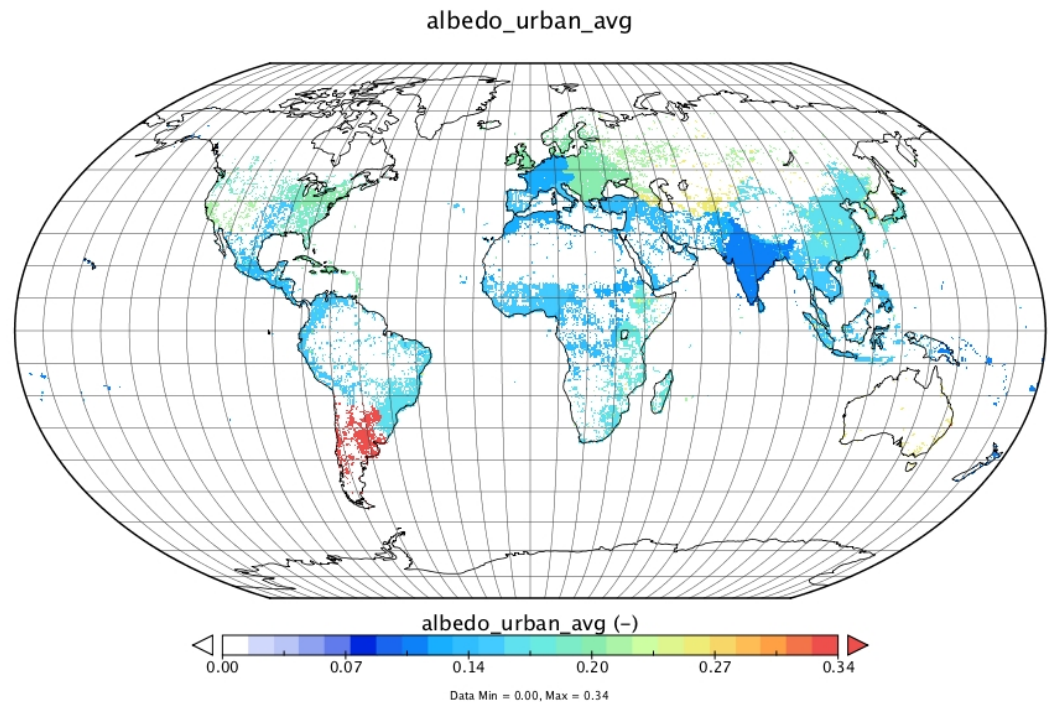


- Focus on response of model to basic urban hydrology
- *Parsimonious approach*
 - Treat as bare soil
 - Modify infiltration by specifying impermeable fraction
 - Specify fixed albedo
 - Specify fixed roughness length (underway – Sud et al 1988)

Urban Albedo

- First thought: use the NCAR urban dataset (Jackson et al. 2010)
- But... ModelE has relatively low albedo values from the 1983 model!

Set urban to lowest vegetation albedo (0.055)



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MONTHLY WEATHER REVIEW

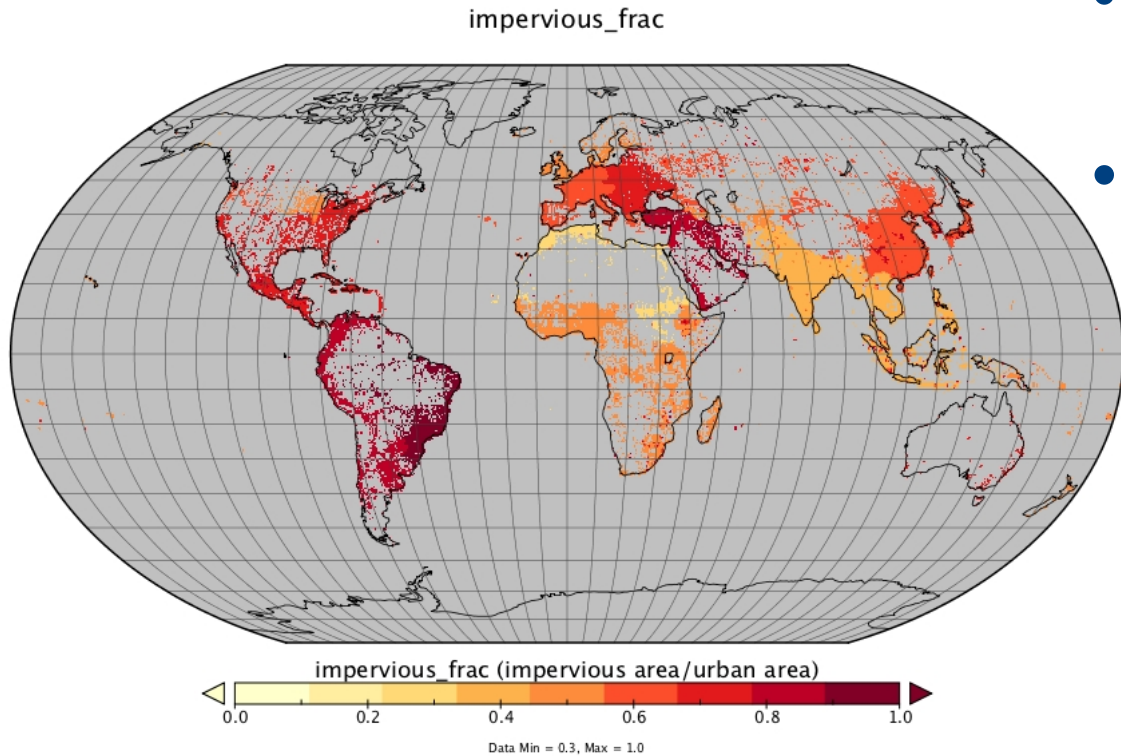
VOLUME 111

TABLE 6. Vegetation characteristics in Model II.

		Desert*	Tundra	Grass	Shrub	Woodland	Deciduous	Evergreen	Rainforest
Visual albedo	Winter	0.35	0.07	0.09	0.09	0.08	0.10	0.07	0.06
	Spring	0.35	0.06	0.10	0.10	0.07	0.05	0.07	0.06
	Summer	0.35	0.08	0.09	0.14	0.08	0.06	0.08	0.06
	Autumn	0.35	0.08	0.09	0.11	0.06	0.05	0.06	0.06
Near-IR albedo	Winter	0.35	0.20	0.27	0.27	0.23	0.30	0.20	0.18
	Spring	0.35	0.21	0.35	0.30	0.24	0.22	0.20	0.18
	Summer	0.35	0.30	0.36	0.42	0.30	0.29	0.25	0.18
	Autumn	0.35	0.25	0.31	0.33	0.20	0.22	0.18	0.18
Field capacity (g m ⁻¹)	Layer 1	10	30	30	30	30	30	30	200
	Layer 2	10	200	200	300	300	450	450	450
Masking depth (m)		0.1	0.2	0.2	0.5	2	5	10	25
Roughness length (m)		0.005	0.01	0.01	0.018	0.32	1	1	2

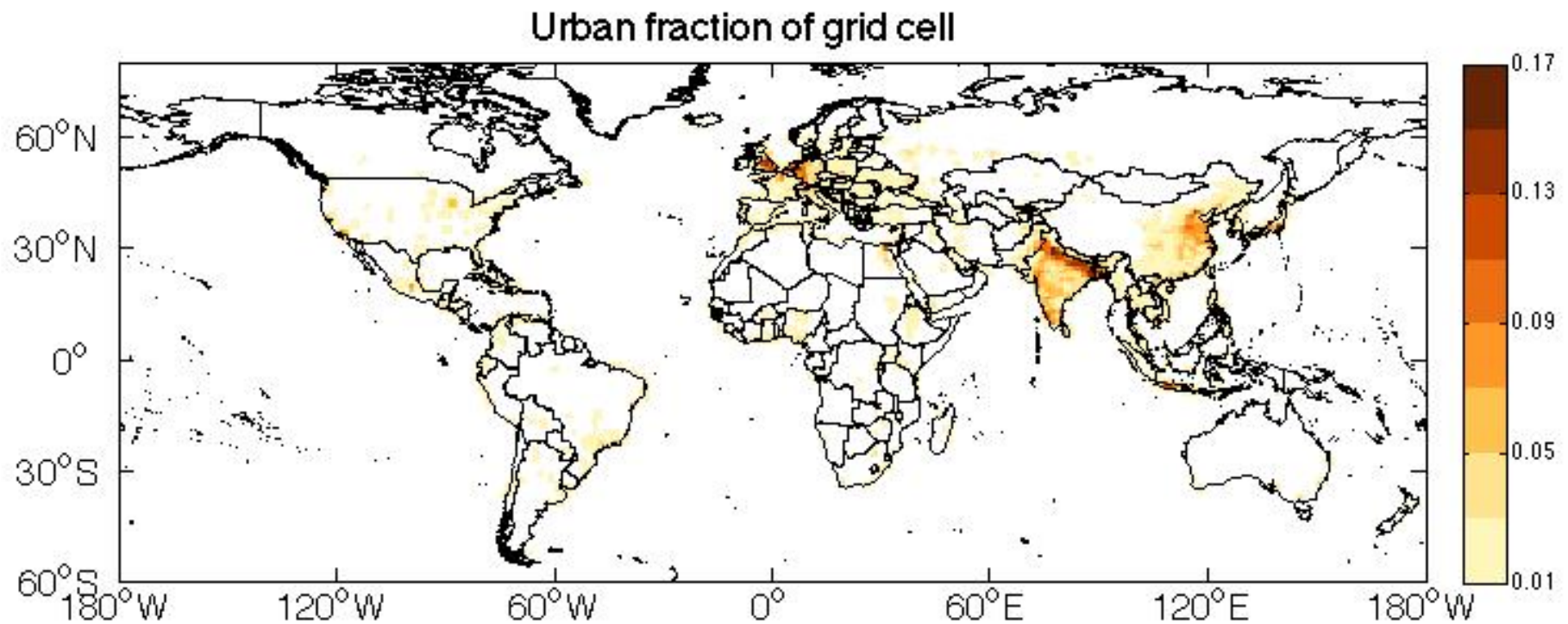
* Desert albedo is reduced by ground wetness by the factor $(1 - 0.5 W_1)$.

Urban impervious fraction



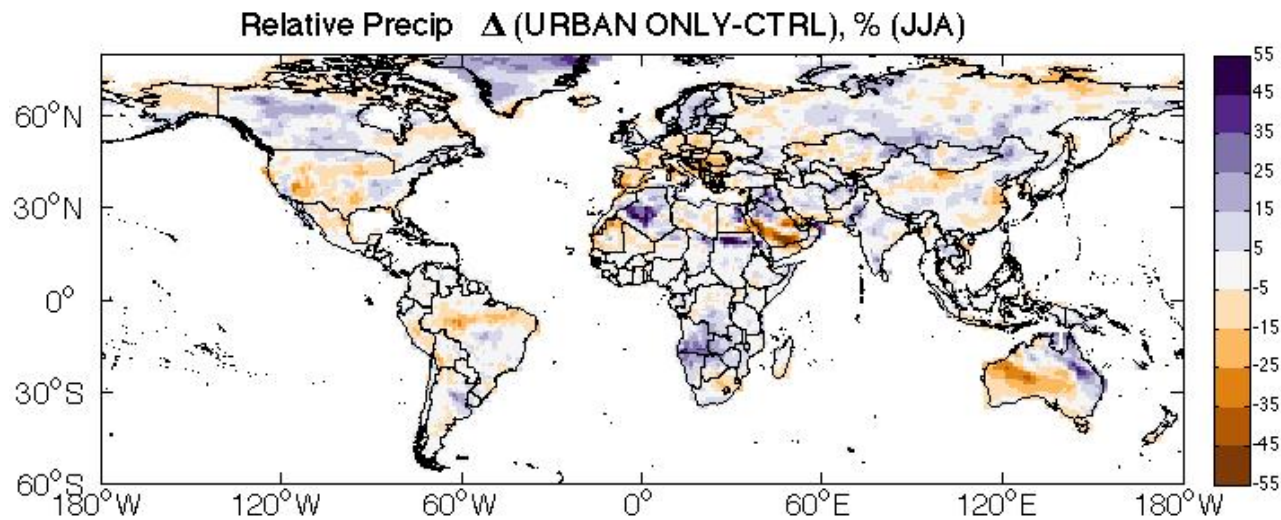
- Based on road and roof fractions
- ModelE is sensitive to the impervious frac.
 - Impermeable (IMPERM) experiment: use NCAR impervious fraction
 - Permeable (PERM) experiment: treat as bare soil

Urban areas



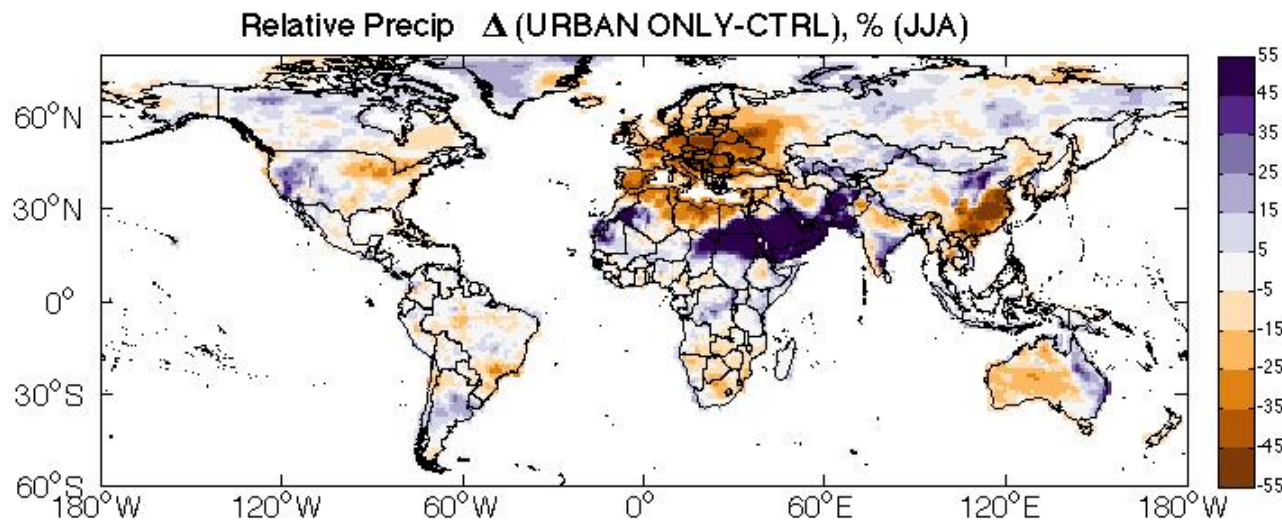
- Three equilibrium runs (CTRL, URBAN_PERM, URBAN_IMPERM)
- 1° lat × 1° lon (cubed sphere)
- Year 2000 GHG and SSTs

Precipitation response



URBAN_PERM
minus
CTRL

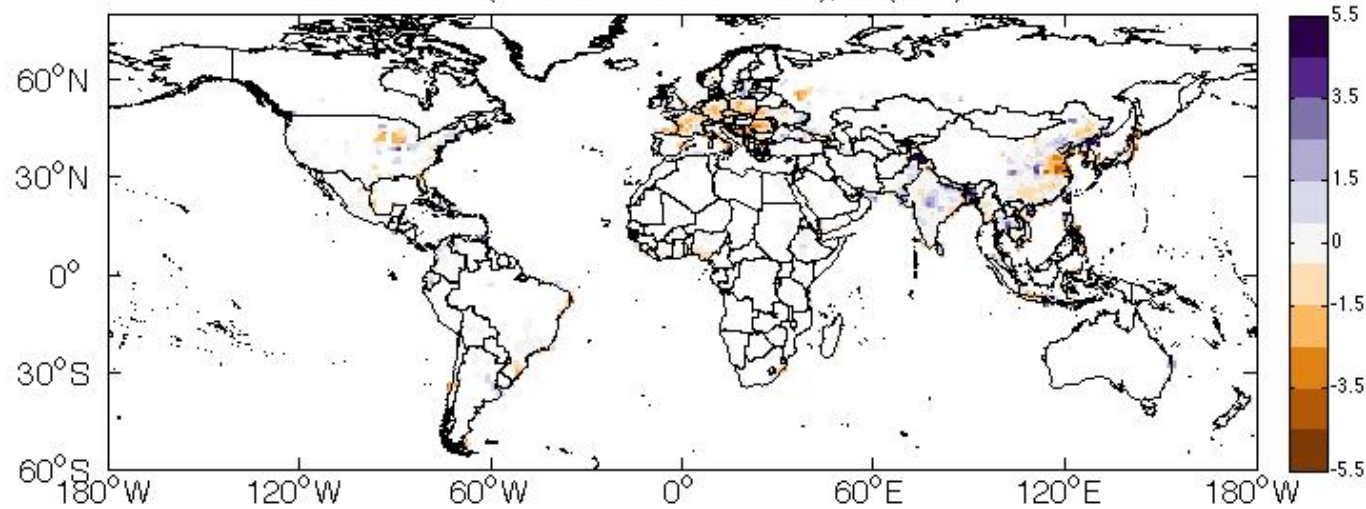
No significance masking



URBAN_IMPERM
minus
CTRL

Runoff ratio (urban cells only)

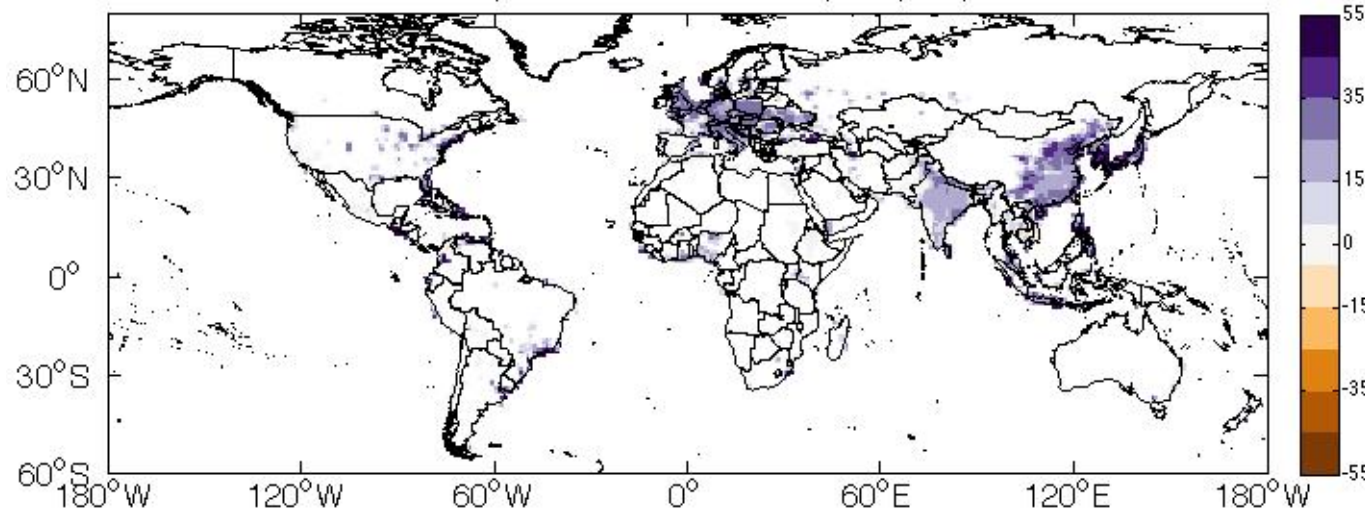
Runoff ratio (URBAN ONLY-CTRL), % (JJA)



URBAN_PERM
minus
CTRL

No significance masking

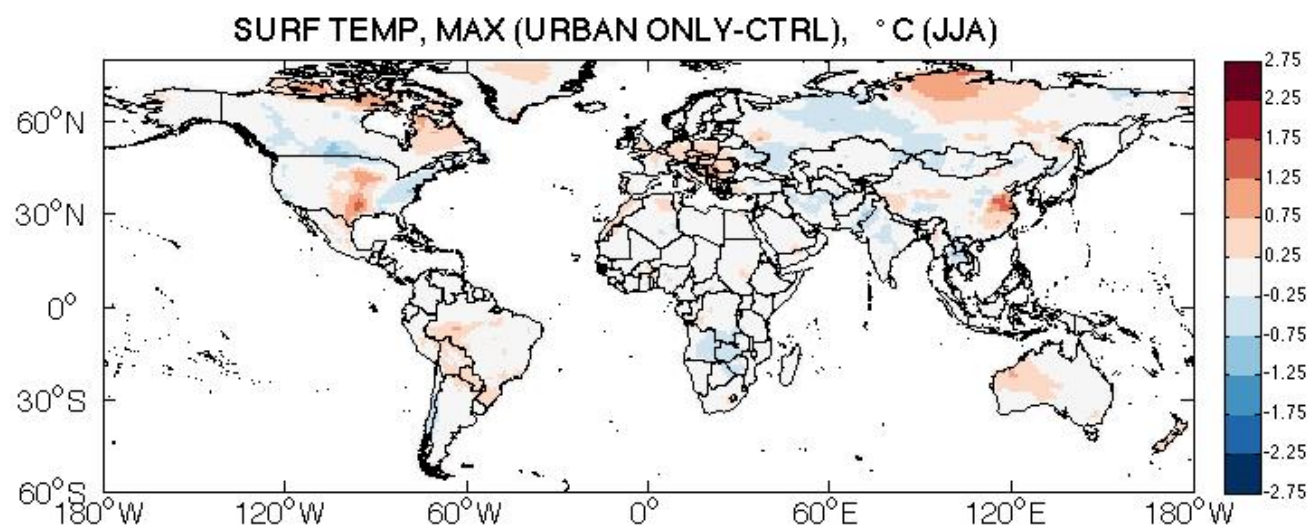
Runoff ratio (URBAN ONLY-CTRL), % (JJA)



Note: scale X 10

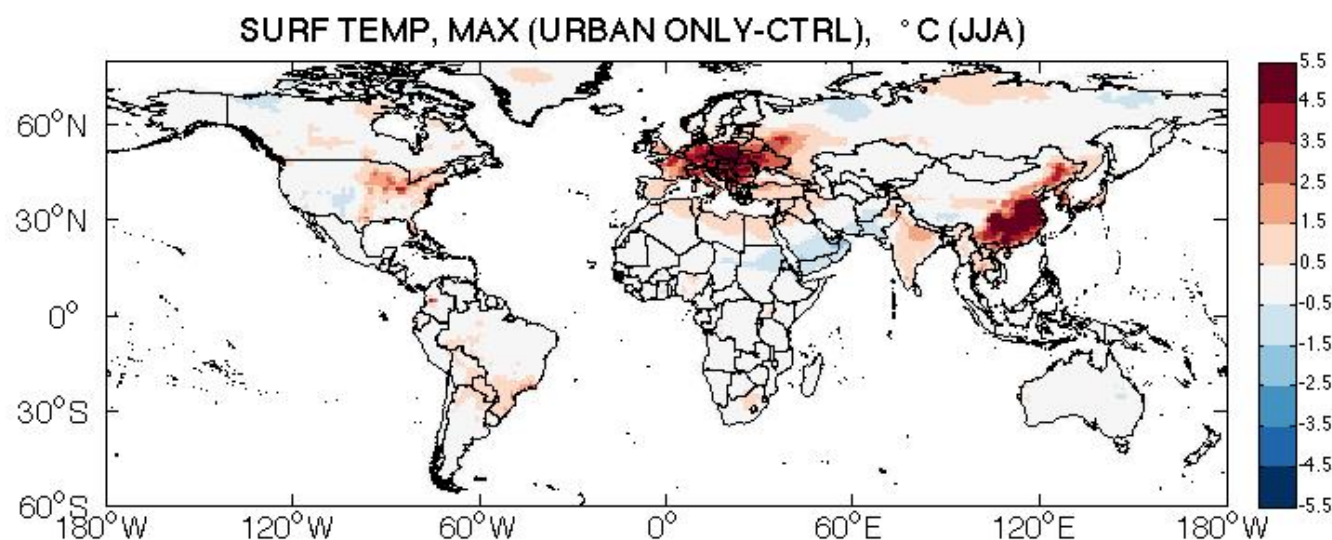
URBAN_IMPERM
minus
CTRL

Maximum daily temperature



URBAN_PERM
minus
CTRL

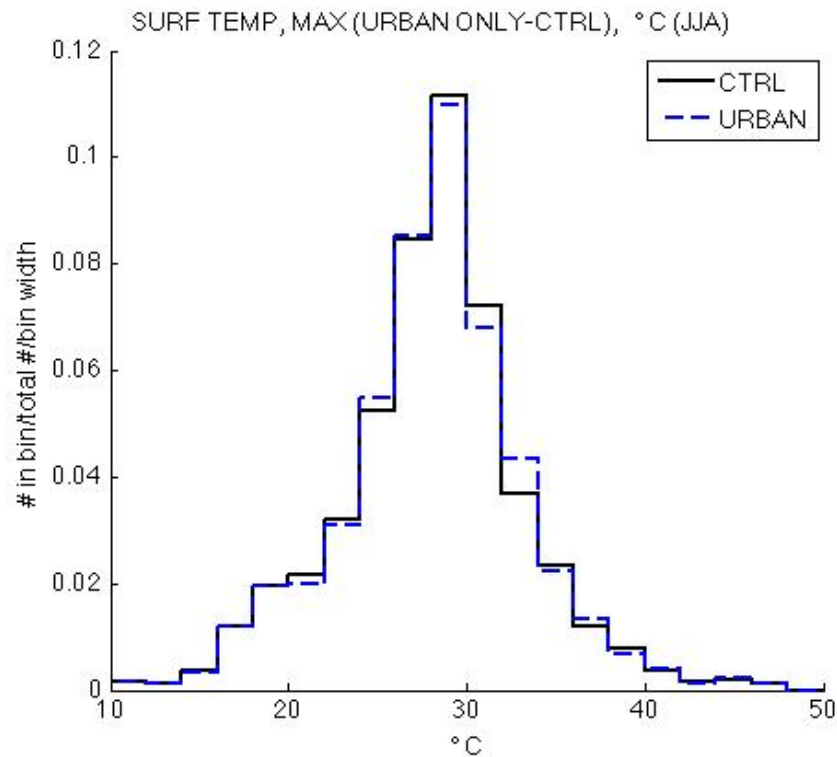
No significance masking



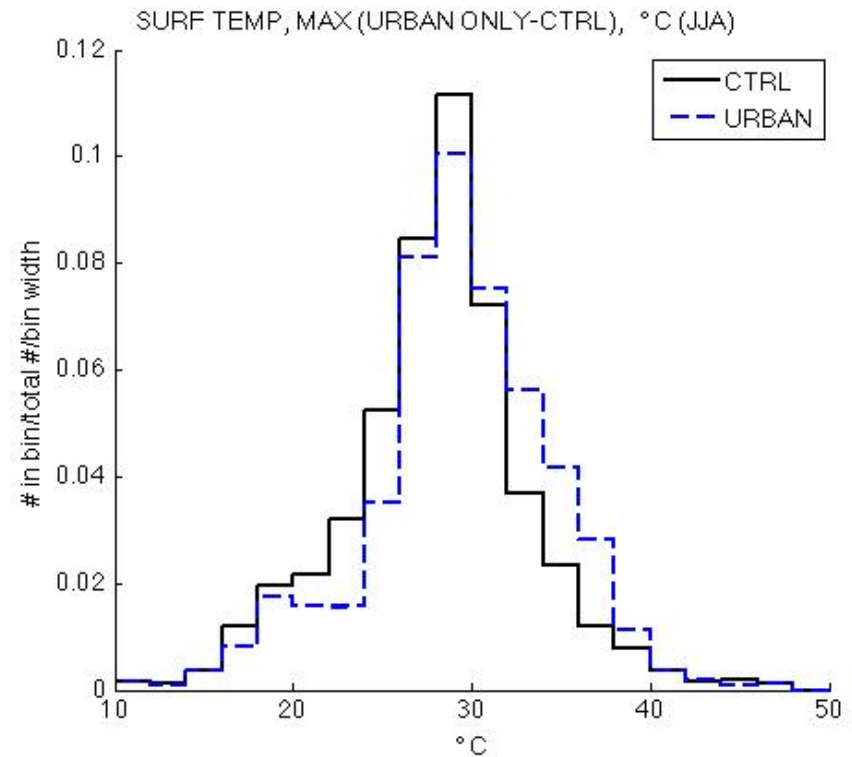
Note: scale X 2

URBAN_IMPERM
minus
CTRL

Urban temperature response



URBAN_PERM - CTRL



URBAN_IMPERM - CTRL

Temperature in Northern Hemisphere Urban Cells

Outline

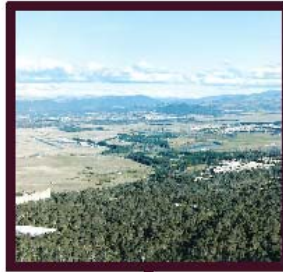
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ModelE Land Surface Model: 'Mosaic' approach

New dynamics

- Agriculture/irrigation
- Urbanization

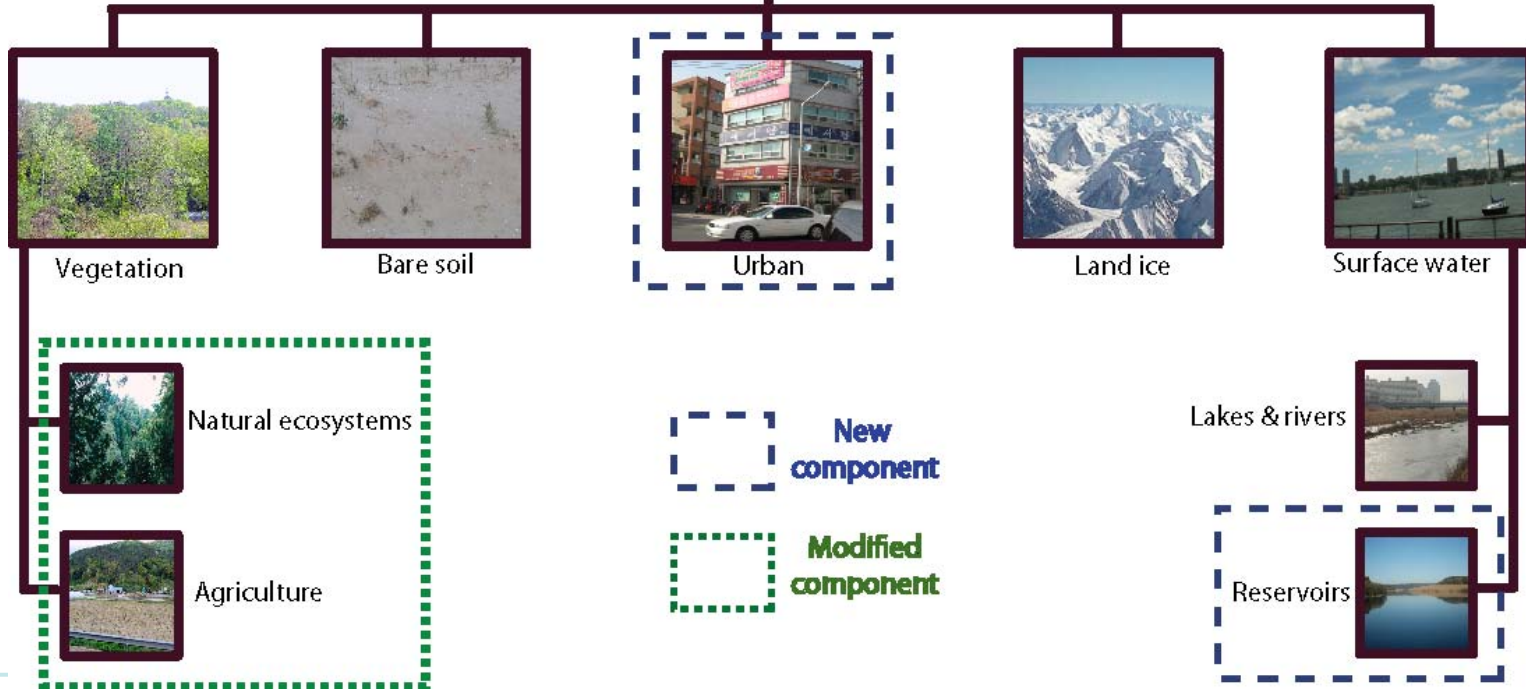
ModelE Grid Cell



Improved soil column

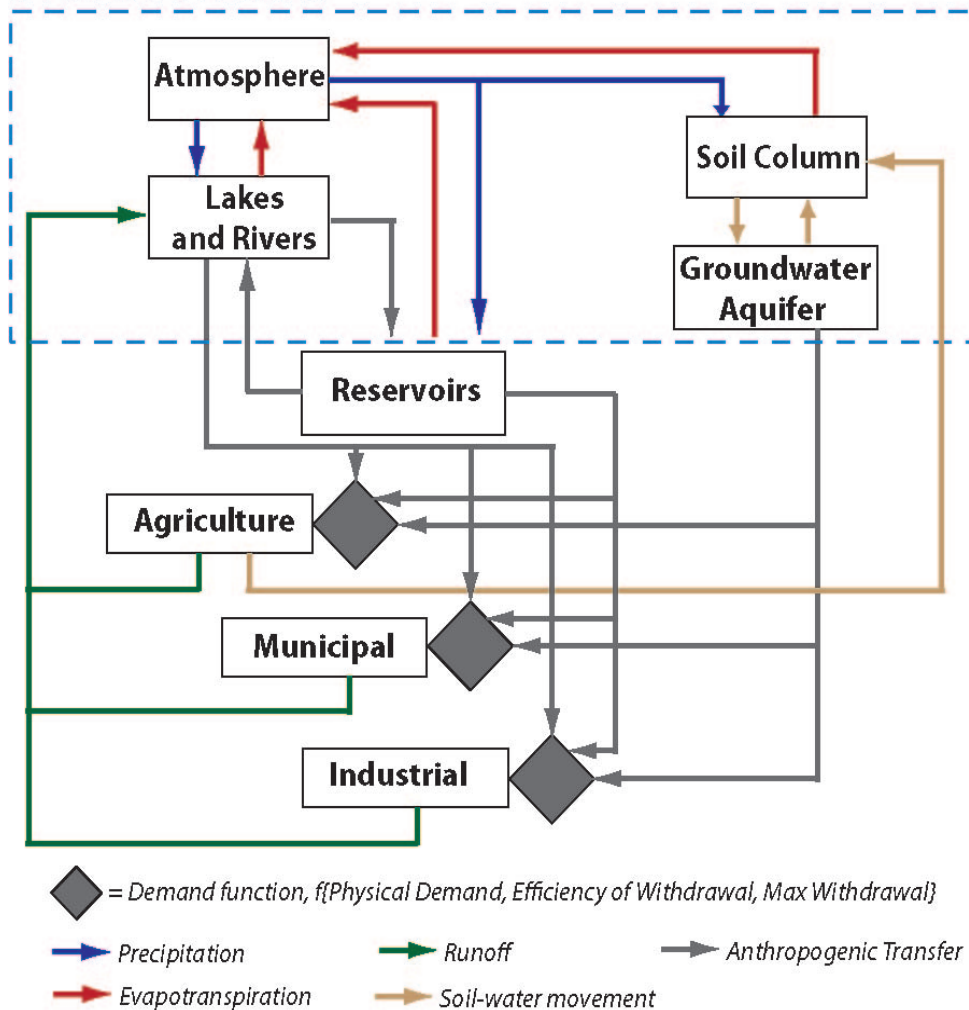
- Plant-water uptake
- Multiple columns
- Deep soil water (aka groundwater)

ModelE Land Fractions

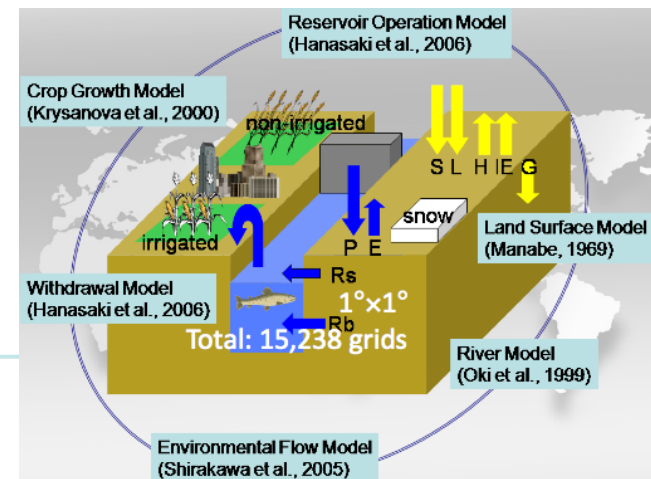


Human control of the terrestrial water cycle

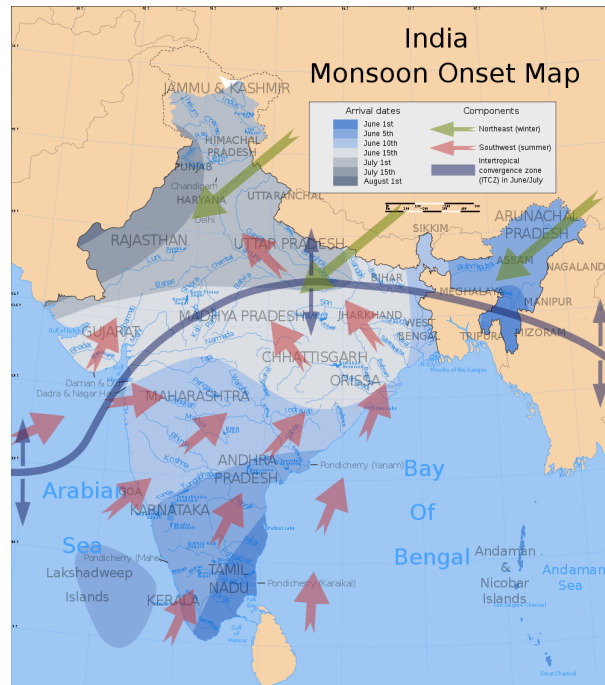
ModelE (2012 Version)



- Few groups (esp. in US) have integrated impact of human activities
 - MIROC GCM (Japan): couples a water resource model (H08) with a GCM land model (MATSIRO)

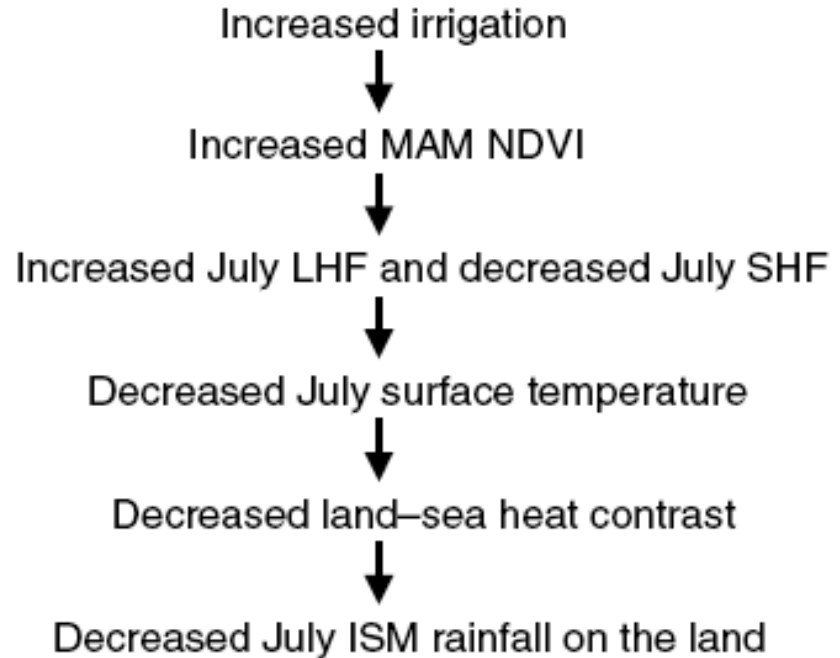


Irrigation and Monsoon Research at GISS



At GISS, Sonali is currently analyzing monsoon dynamics with and without irrigation

- Lee et al (2009) analyzed observed NDVI, precip, and temp data for 1982 to 2003



Climate model simulated changes in temperature extremes due to land cover change

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[1] A climate model, coupled to a sophisticated land surface scheme, is used to explore the impact of land use induced land cover change (LULCC) on climate extremes indices recommended by the Expert Team on Climate Change Detection and Indices (ETCCDI). The impact from LULCC is contrasted with the impact of doubling atmospheric carbon dioxide (CO₂). Many of the extremes indices related to temperature are affected by LULCC and the resulting changes are locally and field significant. Some indices are systematically affected by LULCC in the same direction as increasing CO₂ while for others LULCC opposes the impact of increasing CO₂. We suggest that assumptions that anthropogenically induced changes in temperature extremes can be approximated just by increasing greenhouse gases are flawed, as LULCC may regionally mask or amplify the impact of increasing CO₂ on climate extremes. In some regions, the scale of the LULCC forcing is of a magnitude similar to the impact of CO₂ alone. We conclude that our results complicate detection and attribution studies, but also offer a way forward to a clearer and an even more robust attribution of the impact of increasing CO₂ at regional scales.

- Schaeffer et al., 2005: Potentially enhanced changes in extremes compared to the mean

Information on extremes and climate adaptation

- Luber and McGeehin, 2008: Extreme events changes are likely to have a more significant direct impact on society than changes in the mean
- UNDP's Low Emission Climate-Resilient Development

LECRDS Approach



Preparing Low-emission and Climate-Resilient Development Strategies (LECRDS) - Executive Summary

This report serves as the Executive Summary to a series of manuals and guidebooks that UNDP is offering in support of LECRDS. It provides a brief outline of the approach and methodologies that these materials treat in detail.

Step 1: Develop a Multi-Stakeholder Climate Planning Process



Charting a New Carbon Route to Development

Integrated climate change planning - a how-to guide for local and regional policy-makers on planning a low-carbon future. This document focuses on the importance of full engagement of sub-national authorities to comprehensively address climate change and suggests that taking the necessary action to tackle climate change will be more effective if it helps address local development issues.

Establishing a Multi-stakeholder Decision-making Process for LECRDS (Aug 2011)

Step 2: Prepare Climate Change Profiles and Vulnerability Scenarios



Formulating Climate Change Scenarios to Inform Climate - Resilient Development Strategies

This guidebook builds on a large range of UNDP's ongoing initiatives to support adaptation to climate change. This series is intended to empower decision makers to take action, and to prepare their territories to adapt, and hopefully thrive, under changing climatic conditions.

Questions?

Thanks to my collaborators!!

Thanks to my collaborators!!

NASA Goddard Institute for Space Studies

Benjamin Cook, Maxwell Kelley, Igor Aleinov

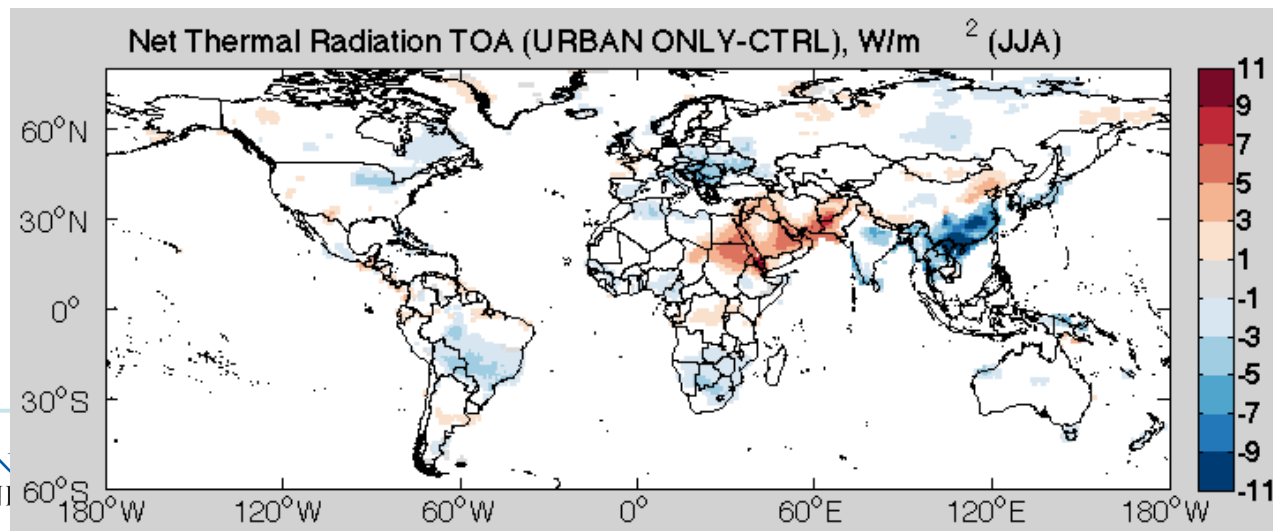
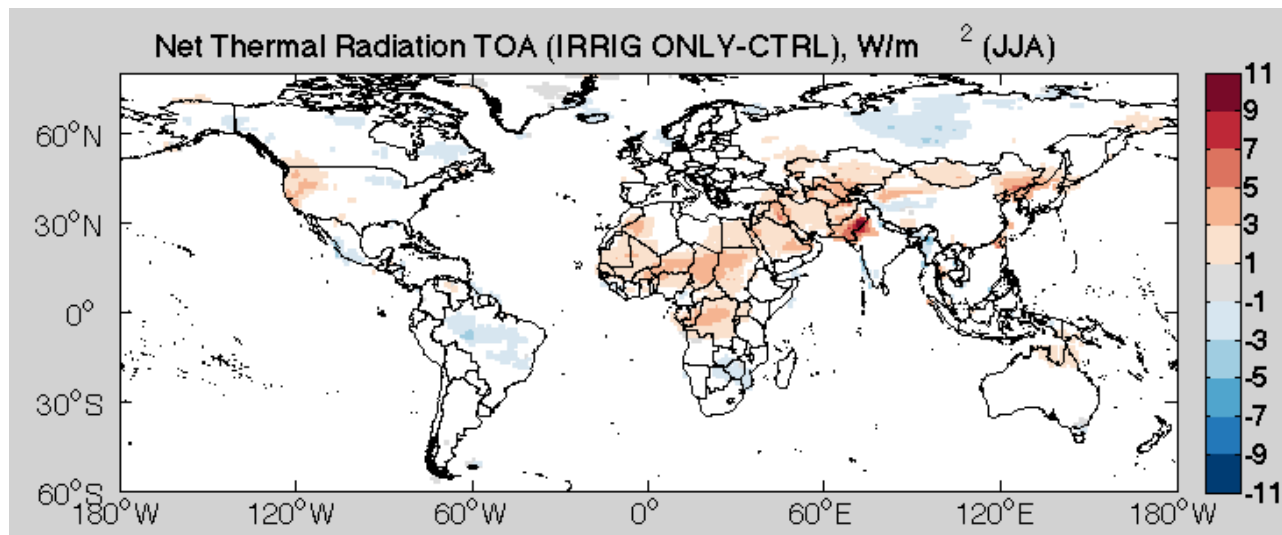
The City College of New York

Nir Krakauer

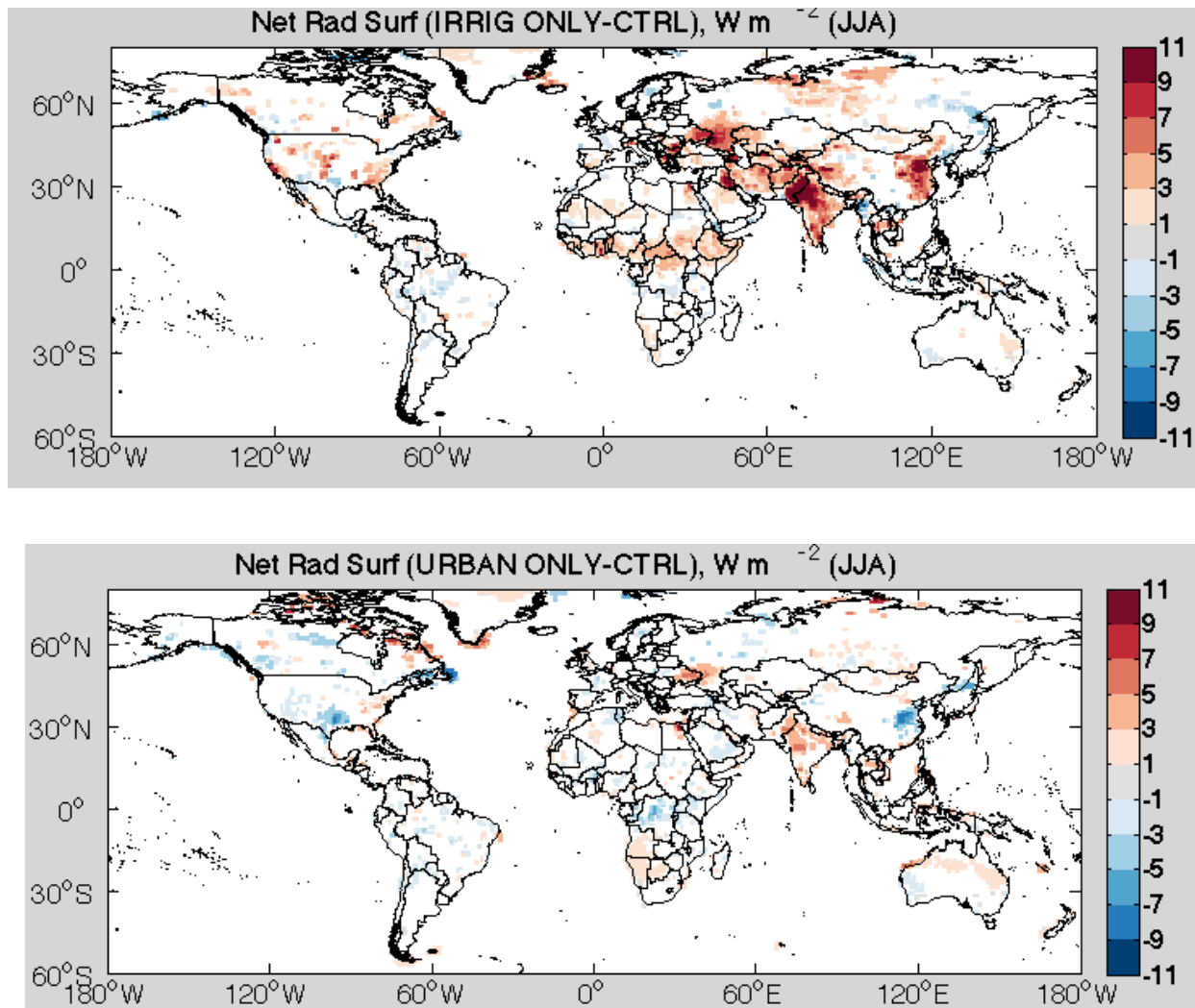
NASA Goddard Space Flight Center

Randy Koster

Net thermal radiation TOA

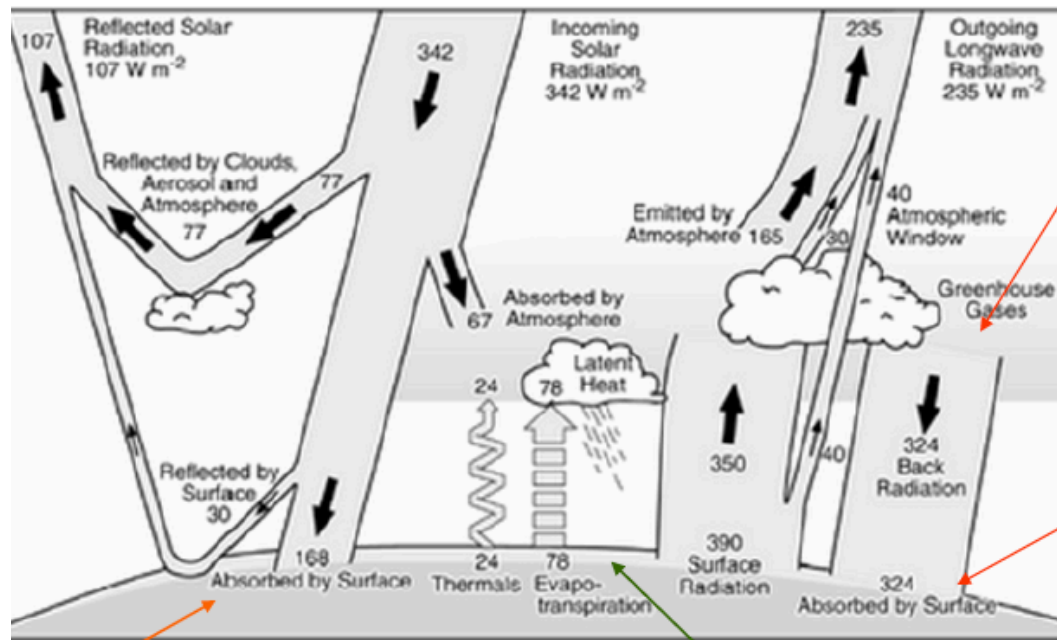


Total net radiation at surface



Introduction

Vegetation cover affects the Earth's energy Balance



CO_2 uptake by vegetation slows the rises in atm' CO_2 concentration, thus lowering downward thermal radiation LWR fluxes. (cooling effect)

Emitted LWR is strongly dependent on the surface temperature.

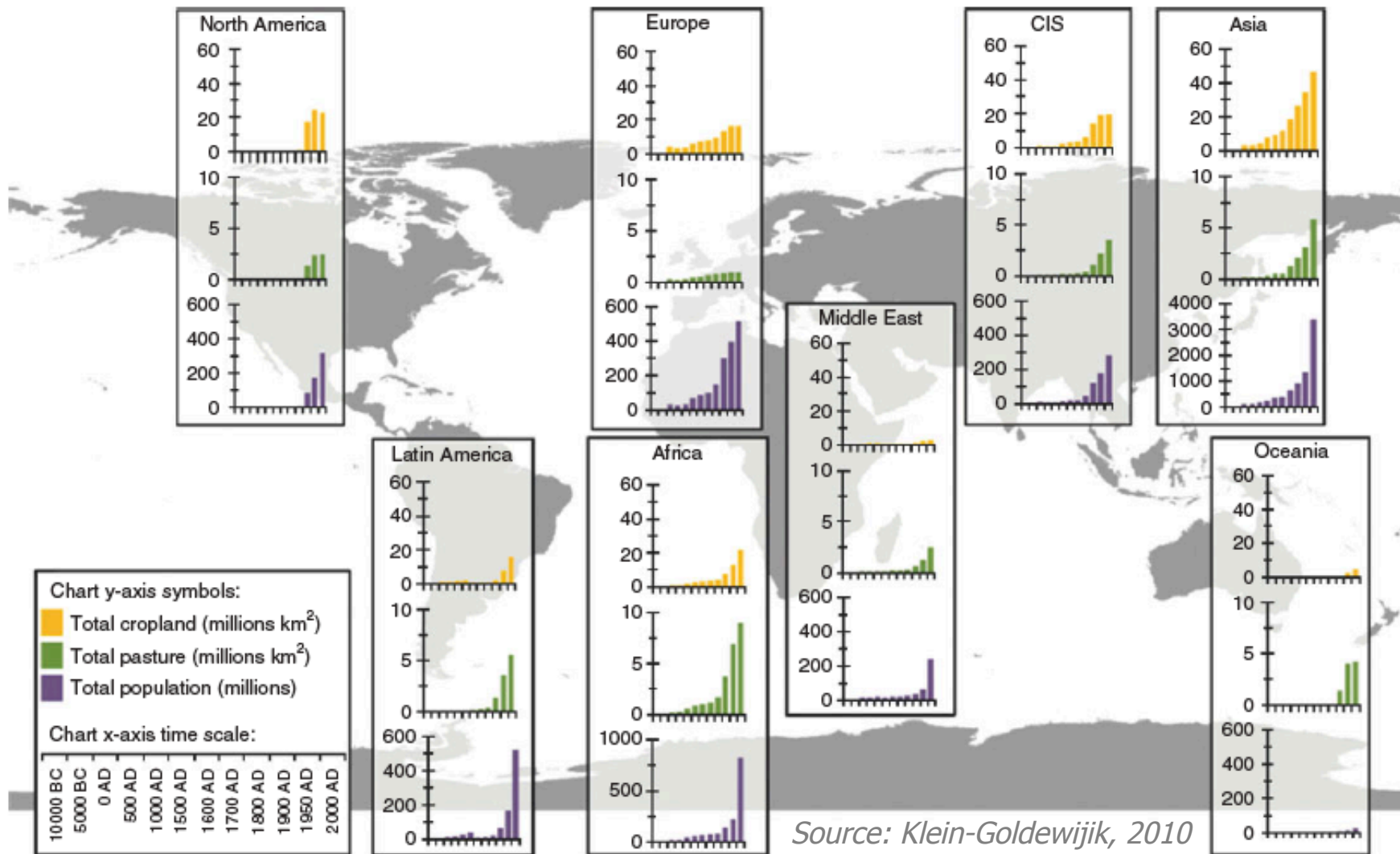
Evaporative surfaces (e. g., vegetation) are usually cooler than bare surfaces in dry areas. (heating effect)

Over land, vegetation cover mostly reduces the albedo. Lower albedo means greater trapping of solar radiation by the Earth surface. (heating effect)

Bowen ratio (sensible/latent heat = β) over land could range from <1 to >10 , it is mostly below 3 for vegetation canopy.

By increasing ET vegetation can enhance precipitation

Historical land change



Source: Klein-Goldewijk, 2010

Potential land change impacts

- **Masking potential:** Suppress the impacts of increasing CO₂ in some regions that cool due to land cover change
 - Miss the detection of a CO₂ signal
- **Amplification potential:** amplify the impacts of increasing CO₂ in regions that warm due to land cover change
 - a false-positive detection of a CO₂ signal